# A systematic review of social contact surveys to inform transmission models of close contact infections

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**Abstract**

Social contact data are increasingly being used to inform models for infectious disease spread with the aim of guiding effective policies on disease prevention and control. In this paper, we undertake a systematic review of the study design, statistical analyses and outcomes of the many social contact surveys that have been published. Our primary focus is to identify the designs that have worked best and the most important determinants and to highlight the most robust findings.

Two publicly accessible online databases were systematically searched for articles regarding social contact surveys. PRISMA guidelines were followed as closely as possible. In total, 64 social contact surveys were identified. These surveys were conducted in 24 countries, and more than 80% of the surveys were conducted in high-income countries. Study settings included general population (58%), schools/universities (37%) and health care/conference/research institutes (5%). The majority of studies did not focus on a specific age group (38%), whereas others focused on adults (32%) or children (19%). Retrospective and prospective designs were used mostly (45% and 41% of the surveys, respectively) with 6% using both for comparison purposes. The definition of a contact varied among surveys, e.g. a non-physical contact may require conversation,

close proximity or both. Age, time schedule (e.g., weekday/weekend) and household size were identified as relevant determinants for contact pattern across a large number of studies. The surveys present a wide range of study designs. Throughout, we found that the overall contact patterns were remarkably robust for the study details. By considering the most common approach in each aspect of design (e.g., sampling schemes, data collection, definition of contact), we could identify a common practice approach that can be used to facilitate comparison between studies and for benchmarking future studies.
**Key words:** contact surveys, contact pattern, infectious diseases, behavioral changes, study design.

# Introduction

Despite the great progress in infectious disease control and prevention that were initiated during the last century, infectious pathogens continue to pose a threat to humanity, as illustrated by SARS, influenza, antimicrobial resistant bacteria, Ebola, and resurgent measles, disrupting everyday life, burdening public health and dominating media headlines well into the 21st century.

Many infectious diseases can spread rapidly between people within and between age groups, households, schools, workplaces, cities, regions and countries through a diversity of social contacts[1]. Understanding and quantifying social mixing patterns is therefore of critical importance to establish appropriate simulation models of the spread of infectious diseases. Such mathematical transmission models have become indispensable to guide health policy. Which interventions should be offered to which people in which circumstances? How would such interventions affect transmission chains and the disease burden throughout the population? What would be the population effectiveness and cost-effectiveness of such interventions? Well-informed answers to these questions require mathematical models. The validity of such models depends heavily on the appropriateness of their structure and their parameters, including what they assume about how people interact.

Indeed, a transmission model's integrated mixing patterns (i.e., who mixes with whom?) have a strong influence on the transmission parameters (i.e., who infects whom?). The latter are the most influential drivers for the outputs of such models. Whereas 20th century models made strong assumptions about mixing patterns, it has become increasingly common to use empirical data on social interactions as a direct model input over the last decade. For sexually transmitted infections, data from surveys on sexual behavior were available for use. For infectious diseases that are transmitted by direct contact, minimal data on relevant social contacts was available for use. A study that aimed to collect precisely this information was conducted using a convenience sample[2]. This study was followed by a study that reported on relevant social contacts in a representative sample of the population that covered all ages in a town[3]. The landmark study that reported on relevant social contacts in representative samples for eight different European countries using contact diaries was the POLYMOD study[4]. Numerous other studies have been reported since. Several of these studies report on social mixing patterns as obtained through direct observation, contact diaries or electronic proximity sensors. The strengths and weaknesses of these methods have been discussed[5]. Nevertheless, a comprehensive review of the study designs for contact diaries, statistical

analyses of social contact data and major determinants of mixing patterns is lacking for this rapidly growing field of research, a gap which we aim to fill here.

In the current paper, we systematically retrieve and review the literature on social contact surveys. First, we provide an overview of the literature to help identify a standard. Second, we present the different approaches for data collection and identify strength and limitations. Third, we report on the main determinants of contact. We use these findings to guide future studies.

# Materials and methods

We conducted a systematic review in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines[6].

**Search strategy**
We queried PubMed and ISI Web of Science, without time and language restriction up to Jan 31, 2018 using the following search string:

*(([survey*] OR [questionnaire*] OR [diary] OR [diaries]) AND ([social contact*] OR [mixing behavio*] OR [mixing pattern*] OR [contact pattern*] OR [contact network*] OR [contact survey*] OR [contact data])*

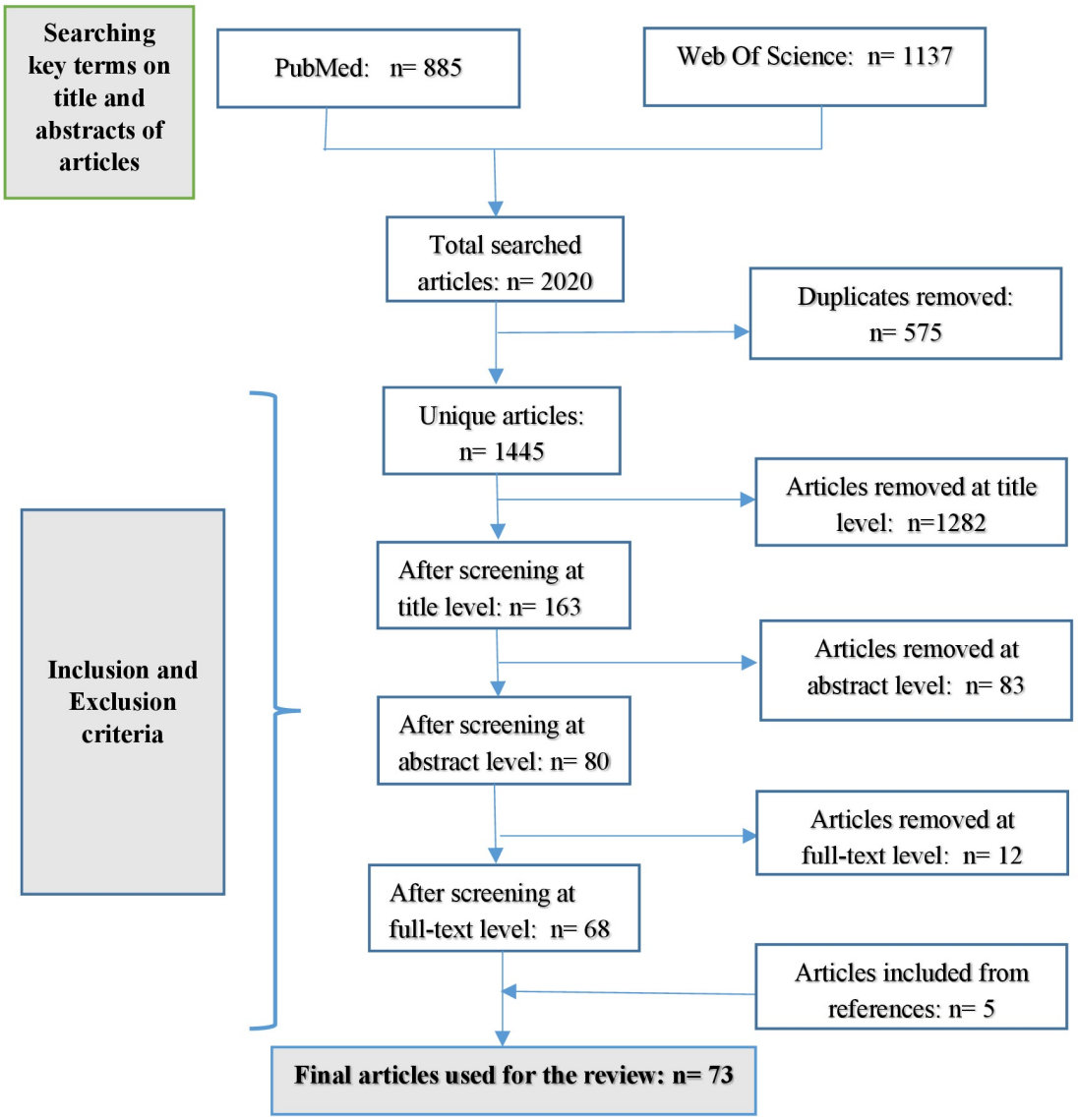
EndNote X7 was used to eliminate duplicates and manage the search results[7].

**Inclusion criteria:** Studies were considered eligible if they fulfilled all of the following criteria: (1) primary focus on face-to-face contacts of humans, implying the physical presence of at least two persons during contact; (2) contacts relevant for the transmission of close-contact infections; (3) contacts recorded using a diary-type system on paper or in electronic format; (4) full-text version available.

**Exclusion criteria:** Studies were excluded if they involved at least one of the following: (1) primary focus on human-animal or animal-animal contacts; (2) recording contacts exclusively relevant for sexually transmitted, food-, vector- or water-borne diseases; (3) using exclusively proximity sensor devices or observational methods to collect contact data; (4) including contacts without physical presence (e.g., phone, internet/social media contacts) or without the possibility to distinguish them; (5) recording the frequency or regularity but not the number of contacts over a given time period; (6) meeting abstracts, books, theses or unpublished journal articles.

An overview of the selection process is presented in Fig 1. Title, abstract and full text were screened initially by the first author and double-checked by the second author in case of doubt.

Figure 1: **The PRISMA flowchart of the search process.**




# Results

### The screening process

After removing 575 duplicates, a total of 1445 unique articles were identified. Using the inclusion and exclusion criteria, 1282 articles were removed at title level and an additional 83 articles were removed at abstract level, yielding 80 articles for full-text screening. At this stage, an additional 12 articles were excluded: 9 did not quantify the number of contacts made in a specific time period, 2 used contact definitions that did not require physical presence and 1 focused exclusively on proximity sensor devices. Using the reference lists of the

68 remaining articles, we identified 5 additional articles. Thus, a total of 73 articles were identified for review (see Fig 1 for more details).

**Country settings**

The 73 remaining articles covered 64 social contact surveys conducted in 24 countries spread over 5 continents: 12 European (Belgium[4,8–10], Finland[4], France[4,11,12], Germany[4,13–16], The United Kingdom (UK)[2,4,17–25], Italy[4], Luxembourg[4], Poland[4], Sweden[26], Switzerland[27,28], The Netherlands[3,4,9,29,30], and The Russian Federation[31]), 5 Asian (China[32–34], Japan[35], Taiwan[36], Thailand[29] and Vietnam[37]), 4 African (Kenya[38], South Africa[39,40], Zambia[39] and Zimbabwe[41], 2 American (Peru[42] and The United States of America[43–47]) and 1 Oceanian country (Australia[48–50]). More details on number of social contact surveys in each of these countries are shown in the global map (see S7 Fig). Only 14 studies were conducted at the whole-country level[4,11,12,24,26,30,35,36], whereas remaining studies focused on a region[10,32,33,37,39,41,45], a city/town[3,34,38,40,49] or a specific setting (school/university, health care facility, etc.) and were therefore not representative of the entire country. Fig 2 demonstrates that 40 out of 64 the surveys were conducted in Europe followed by Asia with 10 surveys. In contrast, only a few surveys were conducted in other regions. In this representation, we count several countries separately, even if they were included as part of a single project[4,9,29,39].

The number of surveys greatly increased over time from only 4 surveys before the year 2000 up to 37 surveys after 2009, indicating that social contact surveys are increasingly conducted. In addition, no survey was conducted outside Europe before 2005. One survey did not indicate the year it was conducted. For this study we used the publication year minus two as a proxy[2].

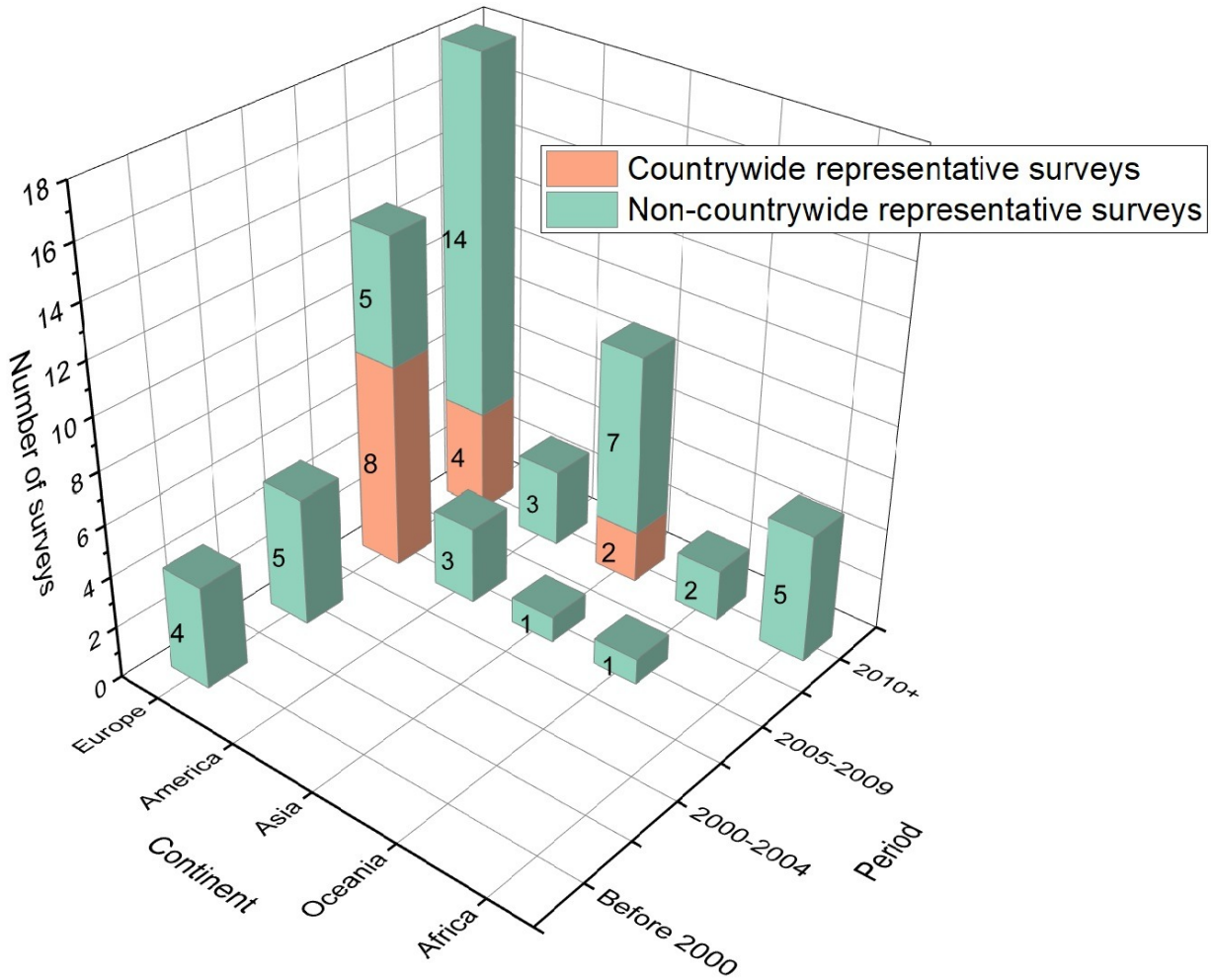
**Study settings and subjects**

Greater than half of the social contact surveys were conducted in the community/general population (58%). Of these, there were only 4 household-based surveys that asked every member of each participating household to complete the survey[12,33,37,42], whereas in other surveys only one person in each participating household was asked to participate. The majority of surveys conducted in the general population aimed at people of all ages (65%)[4,10,12,24–26,30–32,34–38,40–42,45]. In contrast, two surveys excluded infants younger than one year[3], and one excluded children less than two years[33]. Four surveys focused exclusively on adults[27,39,39,49], two survey investigated contact patterns of infants (under 11 weeks [23] and under 1 year old[50]), and one survey aimed at patients with pandemic influenza AH1N1 (swine flu)[18]. More specific settings of schools or universities constituted 38% of the surveys, of which 11 surveys were conducted at schools (primary schools[14], secondary schools[21], high schools [46,47,51–54] and together[18,19,44]) and 13 surveys were performed in universities [2,8,15,17,22,29,31]. Of surveys performed in schools/universities settings, in addition to students serving as main study subjects, staff, family and friends of students were also asked to participate in 6 surveys[2,8,9,22,47]. In addition to school/university settings, we also identified 1 contact survey on nurses in a health-care setting[13], 1 survey at a conference[16] and 1 survey in a research institute [28]. In addition, there were 4 web-based surveys open for anyone to participate, and respondents of these surveys, namely Internet users, are considered as a separate group of study subjects [20,24,55].

**Sample size and response rate**

Among social contact surveys conducted in the general population, the smallest survey only

Figure 2: **Distribution of number of social contact surveys.** Distribution of number of representative surveys based on continents and time periods.




consisted of 54 participants in Switzerland[27], and the largest survey consisted of 5388 participants in the UK[24]. The largest survey in a school/university setting contained 803 participants in Germany[15] (see S1 Fig). The response rate was reported in 36 out of 64 surveys and ranged from 4% in population based surveys[24] up to 100% in a school-based survey[15]. Of these 34 surveys, only 3 considered the response rate beforehand to estimate the sample size[13,36,45]. Fu et al.[36] referred to the average response rates from various nationwide surveys over the past 5 year. These researchers set a goal of 1900 but used a sample of 4207 based on a response rate of 45% for general population-based surveys. DeStefano et al.[45] determined survey response rates using the Council of Survey Research Organization (CASRO) method, leading to 4135 completed interviews, exceeding the goal of 4000. Bernard et al.[13] also assumed a dropout rate of 20% of the initial participants and accounted for that proportion of declining participants. Instead of considering the response rate, some surveys established criteria to substitute those who refused or were not reached after several attempts[37–39]. For example, in a survey conducted by Horby et al.[37], if a selected household declined to participate, the nearest neighbor was approached to participate in the survey. Only one survey[24] presented details on biases in the demographic characteristics of respondents, such

as age, gender and household composition. Specifically, males between 60 and 90 years of age are more likely to appear in the sample, compared with the population distribution; one- and two-person households are overrepresented. Twenty surveys determined sampling weights based on demographic characteristics of the populations to reduce the effects of sample bias[4,9–11,23,24,30,34–39,49].

**Sampling methods**

Approximately half (44%) of the surveys employed convenience sampling, in which subjects were selected based on of their convenient accessibility and proximity to researchers[56]. This sampling technique was also used for the sake of comparing data collection tools[16,47,48,54,57], data collection methods[58] or study designs[8,15,48].

Other sampling techniques can generate samples that can be considered representative for a population but to different extents. Given that random sampling is inherently difficult to implement and generally expensive[56], this technique was used in 7 surveys[3,24,26,32,33,49]. Among these studies, only 2 surveys were considered representative of the entire country[24,26], and the remaining surveys were representative of a region[32,33] or a city/town[3,49]. Given that it is easier to implement and remain representative, multi-stage and stratified sampling were employed in 3 surveys[13,36,37] and 10 surveys[10,12,23,35,38–40,45], respectively. In addition, 10 surveys relied on quota sampling, which aimed to represent certain characteristics of a population, e.g., age, sex, geography, etc. Of these surveys, 9 were conducted at the whole-country level[4,11,30], and one survey focused on one specific region[34]. In addition, one survey used mixed samplings, in which a convenient sample of students was obtained in 2 schools and a random sample of the general population was obtained in one province[31]. When restricted to surveys conducted in the general population, the sampling frames were obtained from a population register/post office address database[4,26,30,33,36–38,40,42], landlines and mobile numbers[4,10–12,45,49] or a list of participants of a larger study[32,35,39,41]. Five surveys used an online respondent-driven method, which can be considered as a snowball/chain sampling technique[29,43,55]. In particular, these surveys used online systems to recruit "seed" participants who were asked to recruit people they know into the surveys. This process was performed until the desired sample size was obtained. Only one survey did not state information on sampling techniques[32]. Finally, 3 surveys conducted at the general population level used a convenience sample[27,42,48], therefore not relying on a sampling frame. More details on the distribution of sampling schemes based on time and regions are presented in S2 Fig.

**Study Design**

By prospective design, we mean that respondents are informed in advance of the day(s) that they are requested to record their contacts[4,15,30]. In a retrospective design, respondents recall their contacts over a past time period without prior warning or instruction that they would be requested to do so. Of 64 surveys, 29 (45%) used a retrospective design, and 26 (41%) used a prospective design. Only 4 surveys ( 6%) used both designs for the purpose of comparison[8,15,48]. For five surveys (8%), it was not completely clear whether the study was prospective or retrospective[18,22,28,46]. S4 Fig displays the trend of using study designs in social contact surveys over time, revealing that the retrospective design was more favored by researchers, except in the period 2005-2009 in which eight prospective surveys were implemented under the same funding source from the European commission project POLYMOD[4,30]. Of the 14 country-wide surveys, the prospective design was employed in 10

surveys,[4,11,24,30] and a retrospective design was employed in 4 surveys[12,26,35,36].

Mccaw et al.[48] compared the prospective design with the retrospective design in the same survey population with a small convenience sample of adult participants. These researchers asked respondents to report their social contacts in 3 typical defined days and compared these data with the results in the same days in the following week, revealing that the prospective design yielded more complete data and more contacts (mean 27.5 versus 15.0). The difference in number of recorded contacts between these two study designs was less pronounced in the work of Mikolajczyk et al. conducted among school children[15]. On average, students recorded two more contacts in the prospective part compared with the retrospective part (asking about a day preceding the survey day) for workdays and one more contact for weekends. Beutels et al[8] observed statistically non-significant differences in average number of contacts made when respondents were asked prospectively on a random day or retrospectively about "yesterday". In this study, 64% of respondents indicated however that the retrospective design was difficult or very difficult, whereas 65% found the prospective diary-based approach to require minimal effort.

**Data collection tools**

Most surveys (83%) used paper diaries to collect contact data. Diaries were delivered and collected by mail in 9 surveys[4,10,11,18,24] and in person in the remaining surveys. Six surveys exclusively used online diaries[9,20,29,43], and 4 surveys used both online and paper diaries[8,24,34,35]. A Personal Digital Assistant (PDA) was used with paper diaries in one survey in 2008[48]. In contrast, proximity sensor devices were used with online diaries in 1 survey in 2012[47] and with paper diaries in 2 surveys in 2013[54] and 201[16]. Most of these studies primarily aimed to explore different social contact data collecting tools.

In contrast to the work of Beutel et al.(2006)[8], which concluded that the paper diary yielded similar results of contact numbers compared with the online diary, Leung et al.[34] showed that participants using paper diary reported on average 9.99 contacts per day, which is substantially increased compared with those using the online diary with only 5.10 contacts per day. In McCaw et al.[48], respondents preferred the paper diary compared with the PDA based on timeliness and completeness. The majority of respondents (63%) described the paper diary as "easy" to use, whereas only 35% respondents had the same opinion regarding the use of PDA. Smiesziek et al.[47] conducted a survey at a high school using both the online diary and wearable proximity sensors, making the two sources of data comparable by matching names of contacts reported by online diaries with names associated with sensor ID numbers. They found the use of online diaries to be more accurate for longer duration contacts but much less accurate for short duration contacts. Mastrandrea et al.[54] and Smiesziek et al.[16] reached similar conclusions comparing paper diaries with wearable proximity sensor devices, with better accuracy for contacts of longer duration using paper diaries. However, there was a distinction in self-reported ease of use with 25% of respondents reporting difficulties in remembering contacts to complete paper diaries, and 25% stating that filling in the diary was too much work. In contrast, 93% respondents felt comfortable having their contacts measured by sensors[16].

**Data Collection methods**

Fifty-two of the 64 surveys (81%), relied on self-reporting, i.e. respondents single-handedly

completed a paper or online diary after receiving oral instructions (in person or via telephone) or written guidelines from investigators. A face-to-face interview was used in nine surveys[3,12,32,33,36,37,39,42] and a Computer-Assisted Telephone Interview (CATI) was employed in three[26,45,49]. Although self-reporting can be used for both retrospective and prospective designs, face-to-face interviews and the CATI only allow for a retrospective design, unless they are supplemented by some form of personal diary keeping that is used during the interview. Akakzia et al.[58] found the paper diary to provide more number of contacts compared with CATI (the median number of reported daily contacts per participant was 13.5 for the paper diaries and 4 for CATI) because it gives the respondent more time to recall contacts. All 4 household-based surveys conducted face-to-face interviews at the respondent's residence[12,33,37,42]. Face-to-face interviews exhibited a greater response rate (46%[36] to 100%[42]) compared with self-reporting and CATI. We could not identify any contact survey directly comparing self-reporting with a face-to-face interview, but different surveys were compared in one work[3] .

**Definition of contact**

Forty (63%) surveys distinguished physical and non-physical contacts. Physical contacts were consistently defined as involving any sort of skin-to-skin touching, e.g., handshake, hug, kiss, etc. The definition of non-physical contacts differed somewhat among surveys. Specifically, the majority of surveys using two types of contacts defined a non-physical contact as a two-way conversation of at least 3 words at a distance that does not require raising one's voice[4,8,34,37,41,48,50,52,58]. In some other surveys, the definition involved close proximity (e.g. verbal communication made within 2 meters) without specification of a minimum number of words to be exchanged[11,24,28,36,39,59]. Of note, that since the POLYMOD contact studies were executed[4], its contact definition was applied in several subsequent surveys[31,34,37,41,42,50,53], both for physical and non-physical contacts. Fifteen surveys used only one type of contact with varying definitions either involving a face-to-face conversation[2,3,14,21,31,43] or being in close proximity within a certain distance (e.g., within one arms length)[29,46,54], both regardless of any skin-to-skin touching[35,47] or only involving direct skin-to-skin touch[26,38]. Nine surveys used more than two types of contact[15,17,27,44]. Only one survey attempted to record casual contacts occurring in an indoor location without the requirement for a conversation or any type of touch[40]. Eight remaining surveys added kissing or intimate sexual contact as different types of contacts[15,17,27,44] or asked respondents to record contacts made in small/large groups or occasional contacts within 2 meters in local transportation or crowded places separately[15].

**Reporting time period**

Greater than half the surveys asked respondents to report contacts they made during a single day, whereas only six surveys used a reporting time period of greater than 3 days. A reporting day was defined in most of these surveys as being either (1) between 5 A.M and 5 A.M the next morning or (2) the time period between getting up and going to bed. The longest time period identified is 3 days in a prospective survey[17,48] and 10 weeks in a retrospective survey[43]. Some surveys recorded both weekdays and weekend days[4,8,17,34,51–53]. These researchers observed marked day-of-week variation. An increased frequency of contacts occur during weekdays with respect to weekends is generally observed. In contrast, the Hong Kong study[34] identified an age-dependent behavior with children and adolescents under 18 also reporting more school contacts during weekends than weekdays. This peculiar

behavior is linked to the specific Hong Kong schooling system, in which students participate in many extra-curricular activities with their schoolmates during weekend[34]. Similarly, several surveys, which were conducted on school-based populations, explored differences in contact patterns between school term or regular periods versus holiday periods[4,18–21,41]. The results from these surveys indicated that school closure is associated with large reductions in the number of contacts and would therefore have a substantial impact on the spread of a newly emerging infectious disease[21,60]. Eames et al[18] quantified the changes in social contact patterns experienced by individuals experiencing an episode of Influenza A(H1N1) on two randomly assigned days: one day while being ill and one day when recovered.

**Characteristics of participants and contactees**

Most surveys collected a range of demographic background characteristics of study participants, e.g., age, gender, education and household size. Some surveys also asked participants to record any influenza-like-illness symptoms they experienced on the day of surveying[29,51,55] or whether their day was in any way special (due to holiday, sickness, etc.)[4,10].

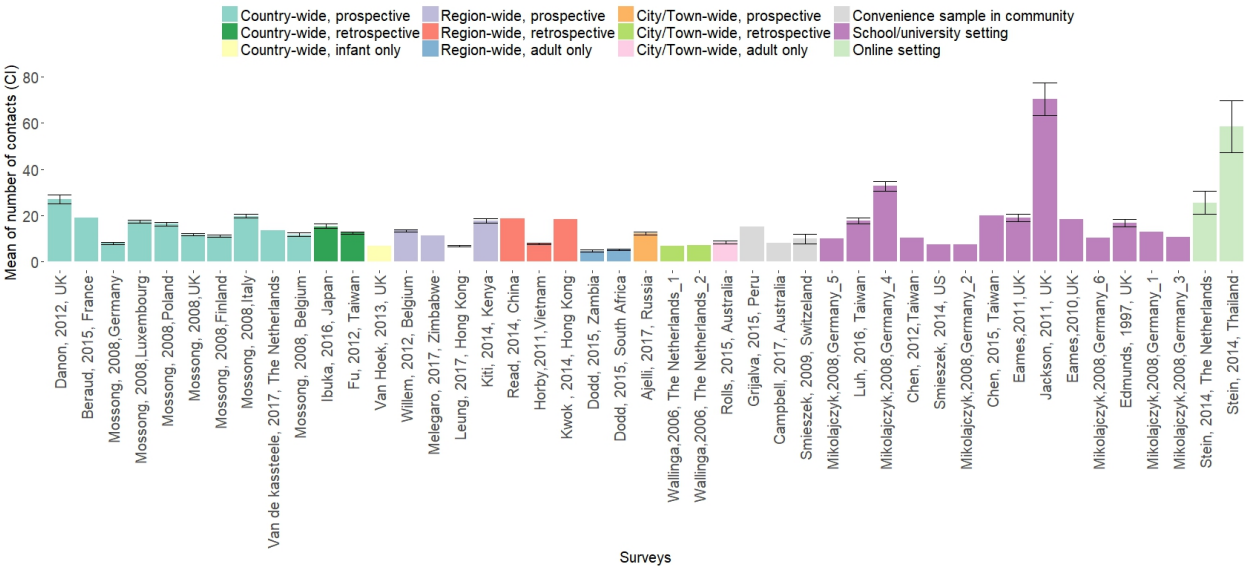
The characteristics of contactees required greater effort given that participants had to remember and/or record anyone they met, even if they were vague acquaintances or first time fleeting encounters. Among the characteristics of contactees, age and gender are considered to be the most important determinants of the mixing patterns given that they can help explain age and gender differences in the epidemiology of infectious diseases[11]. In some surveys, if the participants did not know the exact age of their contacts, they were asked to provide or choose an age range (the mid-point of this range was often used for the purpose of analysis)[2,4,11,30,31,37,53]. Thirty six of 64 (56%) surveys recorded both age and gender of contactees, and 16(25%) surveys recorded only age of contactees. In contrast, 7 (11%) surveys required participants to simply report the number of different contactees without recording any of their characteristics[15,27,43,45,47]. In 5 surveys (8%), it was not clear what contactee characteristics participants had to report[22,24,28,33,46]. Along with age and gender, several surveys also asked participants to record health status of contactees and any symptoms they experienced, e.g., coughing, sneezing, fever,etc.[43,51–53] or whether they wore a protective mask[51,52]. Most of these surveys were conducted in school or university settings using a convenience sample.

**Information about contacts**

Along with information on types and intimacy of contacts (physical or non-physical contacts), the location, duration and frequency of contacts were also studied. Participants were asked to record information about location, duration and frequency of each contact in 77%, 67% and 52% of contact surveys, respectively. If the survey participant met the same person more than once in different contexts during the day, then they were asked to estimate the summed duration and report all of the locations[2,4] . Thirty-four surveys recorded both location and duration. In addition, 29 surveys recorded both location and frequency, and 31 surveys recorded both duration and frequency. All these contact characteristics were jointly recorded in 27 surveys (42%). In addition to this information, several surveys also asked participants to report distance from home of contacts, which could help provide more insight into how infectious diseases spread regionally[10,23,24,33,36].

**Mean number of contacts and analysis of determinants**

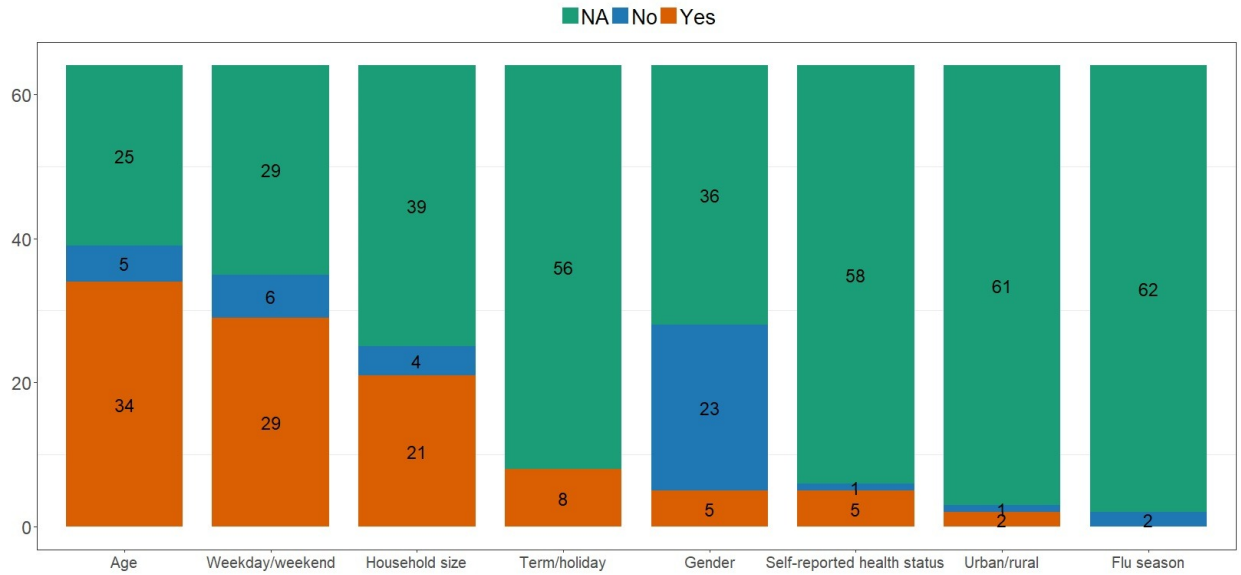
Figure 3: **Average number of contacts among social contact surveys.** Average number of contacts measured and 95% CI. For surveys reporting mean number and standard deviation a 95% CI for the mean was computed. Surveys are labeled according to the publication's first author, year and to the country in which the survey was performed. Ordering is performed based on increasing sample size within the specific design strata.




Of the 64 surveys, 45 explicitly reported the average number of contacts measured without any stratification (Fig 3). To compare these survey results, we categorized them into 12 groups with different extents of representativeness (for country, region or town/city), study designs and settings. In country-wide prospective surveys, the average number of contacts ranges from a minimum of 7.95 ([7.61, 8.29] 95% CI) in Germany[4] to a maximum of 26.97 ([25.05, 28.89] 95% CI) in the UK[24]. In country-wide retrospective surveys, these values ranges from 12.5 ([12.09, 12.91] 95% CI) in Taiwan[36] to 15.3 ([14.4, 16.3] 95% CI) in Japan[35] . Six surveys conducted in the general population asked participants not to report details of professional contacts in the diary but to provide an estimate and age distribution if they had more than 10 contacts (surveys in Finland[4], Germany[4] and the Netherlands[4]) or more than 20 professional contacts (surveys in Belgium[4,10] and France[11]). The additional professional contacts are not included in calculation of means presented in Fig 3. Among school/university-based surveys, the highest number of contact (70.3 [63.23,77.37] 95%CI) was observed in a secondary school in the UK[21]. Only sixteen surveys reported median and quantiles of contacts without any stratification (see S6 Fig).

Fig 4 presents the number of surveys that have analyzed possible determinants for the number of contacts. For every determinant, we report the number of surveys that identified a relevant connection with the number of contacts, the number of surveys that did not identify such a connection and the number of surveys that did not delve into the matter. Strong evidence is identified for the age (34 yes vs. 5 no) and the household size (21 yes vs. 4 no) of the participant to affect the number of contacts. Only 5 surveys identified gender as a relevant indicator for the number of social contact, in contrast to 23 surveys that did not identify a significant relation. Social contacts are also affected from the daily routine (29 yes vs. 6 no) with a larger number of contacts during weekdays compared with the weekend (S5 Fig a,

Figure 4: **Determinants of number of social contacts.** Determinants of number of social contacts. Surveys are tagged as 'Yes' if a relevant connection between the number of contacts and the determinant was identified, 'No' if evidence was not identified , or 'NA' if the given determinant was not analyzed.




with the exception of[34]). Similar results hold for term time versus holidays with all of the 8 surveys analyzing the issue identifying a larger number of contacts during term time (S5 Fig b). In addition, a self-reported healthy status is associated (5 yes vs. 1 no) with a larger number of contacts with respect to feeling ill (S5 Fig c). For example, Eames et al.[18] found that respondents made approximately two-thirds fewer contacts when they were not feeling well compared with when they were feeling well. The relation between social contacts and urbanization has been analyzed in 3 surveys. One survey found a larger number of contacts in peri-urban areas compared with rural areas[41], one found the opposite[38], and one did not find any evidence[33]. Finally, two surveys analyzed contacts during and outside flu seasons. Of these surveys, one survey[45] used a model to adjust for other factors, e.g., age and sex, and one did not[53]. However, both surveys identified no relevant effect (S5 Fig d).
Table 1 provides summaries of all 64 social contact surveys.

Table 1: **Summaries of social contact surveys**

| Nr | Year of finishing | Countries | Authors of first publication | Year of first publication | Study settings | Study subjects | Final sample size | Response rates | Sampling scheme | Data collection tools | Collection modes | Study design | Contact types | Recorded information |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1986 | The Netherlands | Wallinga et al.[3] | 2006 | General population | All excluding 0-1 year | 2106 | 68.3% | Random sampling | Paper diary | Face-to-face interview | Retrospective | 1 | |
| 2 | 1986 | The Netherlands | Wallinga et al.[3] | 2006 | General population | Age 1-70 | 1493 | 29.9% | Random sampling | Paper diary | Self-report | Retrospective | 1 | |
| 3 | 1995 | UK | Edmunds et al.[2] | 1997 | University | Adult (staff, students and their families and friends) | 65 | 70.6% | Convenience sampling | Paper diary | Self-report | Prospective | 1 | Location |
| 4 | 1998 | UK | Read et al.[22] | 2008 | University | Staff and students | 49 | NA | Convenience sampling | Paper diary | Self-report | NA | 2 | Location |
| 5 | 2003 | Belgium | Beutels et al.[8] | 2006 | University | Students and staff | 73 | NA | Convenience sampling | Paper diary and online diary | Self-report on paper and on web interface | Both retrospective and Prospective | 2 | Location |
| 6 | 2003 | Germany | Mikolajczyk et al.[15] | 2008 | University | Students | 38 | 50% | Convenience sampling | Paper diary | Self-report | Retrospective | 6 | Duration, frequency |
| 7 | 2004 | Germany | Mikolajczyk et al.[15] | 2008 | University | Students | 196 | 100% | Convenience sampling | Paper diary | Self-report | Retrospective | 6 | Duration, frequency |
| 8 | 2004 | Germany | Mikolajczyk et al.[15] | 2008 | University | Students | 28 | 100% | Convenience sampling | Paper diary | Self-report | Retrospective | 6 | |
| 9 | 2004 | Germany | Mikolajczyk et al.[14] | 2008 | Primary school | Pupils | 235 | 79.4% | Convenience sampling | Paper diary | Self-report | Retrospective | 1 | Duration, frequency |
| 10 | 2005 | UK | Edmunds et al.[17] | 2006 | University | Students | 29 | 82.9% | Convenience sampling | Paper diary | Self-report | Prospective | 4 | |
| 11 | 2005 | Germany | Mikolajczyk et al.[15] | 2008 | University | Students | 803 | 69% | Convenience sampling | Paper diary | Self-report | Retrospective | 6 | Location |
| 12 | 2006 | Germany | Mikolajczyk et al.[15] | 2008 | University | Students | 115 | 100% | Convenience sampling | Paper diary | Self-report | Both retrospective and Prospective | 6 | Duration, frequency |
| 13 | 2006 | Belgium | Mossong et al.[4] | 2008 | General population | People of all ages | 750 | NA | Quota sampling by age, sex, geographical region, rural/urban | Paper diary | Self-report | Prospective | 2 | Location, duration, frequency |
| 14 | 2006 | Finland | Mossong et al.[4] | 2008 | General population | People of all ages | 1006 | NA | Quota sampling by age and sex | Paper diary | Self-report | Prospective | 2 | Location, duration, frequency |
| 15 | 2006 | Germany | Mossong et al.[4] | 2008 | General population | People of all ages | 1341 | NA | Quota sampling by age | Paper diary | Self-report | Prospective | 2 | Location, duration, frequency |
| 16 | 2006 | Great Britain | Mossong et al.[4] | 2008 | General population | People of all ages | 1012 | NA | Quota sampling by age, sex, geographical region | Paper diary | Self-report | Prospective | 2 | Location, duration, frequency |
| 17 | 2006 | Italy | Mossong et al.[4] | 2008 | General population | People of all ages | 849 | NA | Quota by age, sex, geographical region, rural/urban and day of the week | Paper diary | Self-report | Prospective | 2 | Location, duration, frequency |
| 18 | 2006 | Luxembourg | Mossong et al.[4] | 2008 | General population | People of all ages | 1051 | NA | Quota sampling by age and sex | Paper diary | Self-report | Prospective | 2 | Location, duration, frequency |
| 19 | 2006 | Poland | Mossong et al.[4] | 2008 | General population | People of all ages | 1012 | NA | Quota sampling age, sex, geographical region, rural/urban | Paper diary | Self-report | Prospective | 2 | Location, duration, frequency |

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| Nr | Year of finishing | Countries | Authors of first publication | Year of first publication | Study settings | Study subjects | Sample size | Response rates | Sampling scheme | Data collection tools | Collection modes | Study design | Contact types | Contact information recorded |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 20 | 2006 | The Netherlands | Mossong et al.[4]* | 2008 | General population | People of all ages | 269 | NA | Quota sampling by age and geographical region | Paper diary | Self-report | Prospective | 2 | Location, duration, frequency |
| 20 | 2006 | The Netherlands | van de Kassteele at al.[30]* | 2017 | General population | People of all ages | 825 | NA | Quota sampling based on age and geographical region | Paper diary | Self-report on paper | Prospective | 2 | Location, duration and frequency |
| 22 | 2007 | Germany | Bernard et al.[13] | 2009 | Hospital | Nurses | 131 | 82% | Multi-stage sampling | Paper diary | Self-report | Prospective | 2 | Location, duration, frequency |
| 23 | 2007 | US | Glass et al.[44] | 2008 | School | Pupils | 249 | NA | Convenience sampling | Paper diary | Self-report | Retrospective | 4 | |
| 24 | 2007 | Vietnam | Horby et al.[37] | 2011 | General population | People of all ages | 865 /264 Hhs | NA | Multi-stage sampling | Paper diary | Face-to-face interview | Retrospective | 2 | Location, duration, frequency |
| 25 | 2008 | US | DeStefano et al.[45] | 2011 | General population | People of all ages | 4135 | 21.7% | Stratified sampling | Electronic questionnaire | Computer assisted telephone interview | Retrospective | 2 | Location |
| 26 | 2008 | Australia | Mccaw et al.[48] | 2010 | General population | University employees | 65 | NA | Convenience sampling | Paper diary and A hand-held electronic diary | Self-report | Both retrospective and Prospective | 2 | Location, duration |
| 27 | 2009 | US | Potter et al.[46] | 2012 | High schools | Pupils | 246 | 57.9% | Convenience sampling | Paper diary | Self-report | NA | 1 | |
| 28 | 2009 | Switzeland | Smieszek et al.[27] | 2009 | General population | Adult | 54 | NA | Convenience sampling | Paper diary | Self-report | Retrospective | 3 | Duration |
| 29 | 2010 | Taiwan | Chen et al.[51] | 2012 | Junior high school | Pupils | 274 | 67% | Convenience sampling | Paper diary | Self-report | Prospective | 2 | Location, duration, frequency |
| 30 | 2010 | Great Britain | Danon et al.[24] | 2012 | General population | People of all ages | 5388 | 3.8% | Random sampling | Paper diary and web-based questionnaires | Self-report | Prospective | 2 | Location, duration, frequency |
| 31 | 2010 | UK | Eames et al.[18] | 2010 | Schools | Pupils | 119 | 10.8% | Convenience sampling | Paper diary | Self-report | NA | 2 | Location, duration, frequency |
| 32 | 2010 | UK | Eames et al.[19] | 2011 | Primary and secondary schools | Pupils | 135 | 12.3% | Convenience sampling | Paper diary | Self-report | Prospective | 2 | Location, duration, frequency |
| 33 | 2010 | UK | Eames et al.[18] | 2010 | General population | Patients | 317 | 10.6% | Convenience sampling | Paper diary | Self-report | NA | 2 | Location, duration, frequency |
| 34 | 2010 | UK | Eames et al.[20] | 2012 | General population | Internet users | 3338 | NA | Convenience sampling | Online diary | Self-report on web interface | Retrospective | 2 | Location |
| 35 | 2010 | Taiwan | Fu et al.[36] | 2012 | General population | People of all ages | 1943 | 46.2% | Three-stage systematic probability sampling | Paper diary | Face-to-face interview | Retrospective | 2 | Location, duration, frequency |
| 36 | 2010 | UK | Jackson et al.[21] | 2011 | Secondary schools | Pupils | 107 | 83.6% | Convenience sampling | Paper diary | Self-report | Retrospective | 1 | Location |
| 37 | 2010 | South Africa | Johnstone et al.[40] | 2011 | General population (a town) | People of all ages | 571 | 77.4% | Stratified sampling by age groups | Paper diary | Self-report | Prospective | 3 | Location, duration, frequency |

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| Nr | Year of finishing | Countries | Authors of first publication | Year of first publication | Study settings | Study subjects | Sample size | Response rates | Sampling scheme | Data collection tools | Collection modes | Study design | Contact types | Contact information recorded |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 38 | 2010 | Hong Kong | Kwok et al.[32] | 2014 | General population | People of all ages | 770 | NA | Random Sampling | Paper diary | Face-to-face interview | Retrospective | 2 | Location, duration |
| 39 | 2010 | France | Lapidus an et al.[12] | 2012 | General population | People of all ages | 1377/601 hhs | NA | Stratified sampling by geography | Paper diary | Face-to-face interview | Retrospective | 2 | Location, duration |
| 40 | 2010 | China | Read et al.[33] | 2014 | General population | Greater than 2 years old | 1821/856 hhs | NA | Random sampling of hhs | Paper diary | Face-to-face interview | Retrospective | 2 | Location, duration, frequency |
| 41 | 2010 | Switzeland | Smieszek et al.[28] | 2012 | Research Institute | Staffs | 50 | NA | Convenience sampling | Paper diary | Self-report | NA | 2 | Duration |
| 42 | 2011 | Australia | Campbell et al.[50] | 2017 | General population | Mothers with an infant | 220 | 97.34% | Convenience sampling | Paper diary | Self-report on paper | Prospective | 2 | Location, duration |
| 43 | 2011 | South Africa | Dodd et al.[39] | 2015 | General population | Adults | 1272 | NA | Stratified sampling | Paper diary | Face-to-face interview | Retrospective | 2 | Location, duration, frequency |
| 44 | 2011 | Zambia | Dodd et al.[39] | 2015 | General population | Adults | 2256 | NA | Stratified sampling | Paper diary | Face-to-face interview | Retrospective | 2 | Location, duration, frequency |
| 45 | 2011 | Peru | Grijalva et al.[42] | 2015 | General population | People of all ages | 588/114 hhs | 100% | Convenience sampling | Paper diary | Face-to-face interview | Retrospective | 2 | Location, duration, frequency |
| 46 | 2011 | Japan | Ibuka et al.[35] | 2016 | General population | People of all ages | 3146 | NA | Convenience sampling | Online and paper diaries | Self-report | Retrospective | 1 | Location, duration |
| 47 | 2011 | Belgium | Willem et al.[10] | 2012 | General population | People of all ages | 1752 | NA | Stratified sampling by age and geography | Paper diary | Self-report | Prospective | 2 | Location, duration, frequency |
| 48 | 2012 | France | Beraud et al.[11] | 2015 | General population | People of all ages | 2033 | 51.1% | Quota sampling for age, gender, days of week and school holiday | Paper diary | Self-report | Prospective | 2 | Location, duration, frequency |
| 49 | 2012 | Kenya | Kiti et al.[38] | 2014 | General population | People of all ages | 568 | 50.1% | Stratified random sampling | Paper diary (Text and pictorial diary) | Self-report | Prospective | 1 | Location, frequency |
| 50 | 2012 | US | Smieszek et al.[47] | 2014 | High schools | Pupils, teachers and other staff | 256 | 26.3% | Convenience sampling | Online diary and proximity sensors | Self-report on web interface | Retrospective | 1 | Duration |
| 51 | 2012 | Sweden | Stromgren et al.[26] | 2017 | General population | People of all ages | 694 | 43.8% | Random sampling | Paper diary | Telephone interview | Prospective | 1 | Location |
| 52 | 2012 | UK | Van Hoek et al.[23] | 2013 | General population | Infant (under 11 weeks) | 115 | 11.5% | Random sampling | Paper diary | Self-report | Prospective | 2 | Location, duration, frequency |
| 53 | 2013 | US | Aiello et al.[43] | 2016 | University/residence halls | Students | 590 | NA | Randomized clusters of residence halls, snowball sampling | Online diary | Self-report on web interface | Retrospective | 1 | Location, duration |
| 54 | 2013 | Taiwan | Chen et al.[52] | 2015 | Junior high school | Pupils | 150 | 44% | Convenience sampling | Paper diary | Self-report | Prospective | 2 | Location, duration and frequency |

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| Nr | Year of finishing | Countries | Authors of first publication | Year of first publication | Study settings | Study subjects | Sample size | Response rates | Sampling scheme | Data collection tools | Collection modes | Study design | Contact types | Contact information recorded |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 55 | 2013 | Taiwan | Luh ad et al.[53] | 2016 | Junior high school | Pupils | 373 | 44.37% ÷ 66.26% | Convenience sampling | Paper diary | Self-report | Prospective | 2 | Location, duration and frequency |
| 56 | 2013 | France | Mastrandrea et al.[54] | 2015 | High school | Students | 120 | 31.7% | Convenience sampling | Paper diary and proximity sensors | Self-report | Prospective | 1 | Duration |
| 57 | 2013 | Zimbabwe | Melegaro et al.[41] | 2017 | General population | People of all ages | 1245 | 86.3% | Stratified sampling | Paper diary | Self-report on paper | Prospective | 2 | Location |
| 58 | 2013 | Australia | Rolls et al.[49] | 2015 | General population | Adults | 1307 | 33.5% | Random sampling | Electronic questionnaire | Computer assisted telephone interview | Retrospective | 2 | Location, duration |
| 59 | 2013 | Thailand | Stein et al.[29] | 2014 | University | Students and their friends | 220 | 85.6% | Online respondent driven sampling | Online diary | Self-report on web interface | Retrospective | 1 | Location |
| 60 | 2013 | The Netherlands | Stein et al.[29] | 2014 | University | Students and their friends | 322 | 89.9% | Online respondent driven sampling | Online diary | Self-report on web interface | Retrospective | 1 | Location |
| 61 | 2014 | Germany | Smieszek et al.[16] | 2016 | Conference | Adult | 74 | 24.7% | Convenience sampling | Paper diary and proximity sensors | Self-report and wearable proximity sensor | Prospective | 2 | Duration |
| 62 | 2014 | The Netherlands | Stein et al.[9] | 2015 | General population | Internet users | 1451 | NA | Online respondent driven sampling | Online diary | Self-report on web interface | Retrospective | 2 | Location |
| 63 | 2014 | Belgium | Stein et al.[9] | 2015 | General population | Internet users | 109 | NA | Online respondent driven sampling | Online diary | Self-report on web interface | Retrospective | 2 | Location |
| 64 | 2015 | Hong Kong | Lyung et al.[34] | 2017 | General population | People of all ages | 1149 | NA | Quota sampling by age and sex | Paper diary and online diary | Self-report on paper and web interface | Both prospective and retrospective | 2 | Location, duration and frequency |
| 65 | 2016 | Russia | Ajelli et al.[31] | 2017 | General population | People of all ages | 505 | NA | Mixed samplings | Paper diary | Self-report | Prospective | 1 | Location |

[*] As the multi-country survey was published while data collection was still on-going in the Netherlands, only 269 of these 825 participants were included in the study published by Mossong et al. (2008) [4]. These 269 participants were also included in the study published by van de Kassteele et al.(2017) [30]. Therefore, even if these studies are listed separately in this table, only one survey is counted.

# Discussion and conclusion

Social contact surveys are increasingly used to collect empirical data on human contact behavior and provide crucial inputs for mathematical models of infectious disease transmission. The POLYMOD project[4] presented the first large scale representative population surveys conducted in 8 European countries. It also shared know-how both for data collection and analysis.

To date, most of these contact surveys were conducted in high and middle-income countries, whereas low-income countries, which have a higher burden of communicable diseases, were less studied in this respect. In view of this notion, there is a need to continue studying contact patterns more widely and in particular in low- and middle-income settings. It is also worth noting that in low- and middle-income countries, the choice to perform a general population representative survey may be less meaningful, given the large variety of different settings (urban,rural, etc) that are simultaneously present. Therefore, the decision for sampling specific areas can be deliberate and aimed at sampling social contact interactions in an area with distinct and more specific socio-demographics characteristics.

The use of an appropriate sample size is of importance to any study[56]. Most surveys did not clearly present sample size calculations, so we do not know to which extent important parameters, e.g. , population size, confidence level and margin of error, were taken into account[61]. Sample size estimation is even more important when one wants to compare social contact surveys between or among populations. Given the lack of a clear picture regarding which demographical and anthropological factors are relevant in shaping contact patterns, inherent factors that may drive contact patterns are difficult to account for, thus making comparison among large populations, e.g. countries, even more difficult. In addition, the response rate or the substitution scheme also need to be considered to ensure that the number of study participants is obtained as initially planned. Indeed, the proportion of people who chose not to participate in surveys was quite high (on average 42.9%), particularly in general population-based surveys[11,20,23,24,45]. The extensive analysis of this review has underlined a general lack of information on response rates, and a call for a better non-response analysis emerges as a guideline for future studies.

The prospective design is subject to less recall bias than the retrospective design. This notion can be partly explained by the fact that respondents in the former are informed in advance about which days they will be assigned for reporting their contact information. Furthermore, they are also asked to keep a diary with them and finish reporting before the surveying day is elapsed. Thus, the prospective design requires more commitment from respondents. However, in return, a prospective design can obtain more reported contacts compared with retrospective design[15,48]. However, large-scale studies are needed to confirm this conclusion.

Each data collection tool has its own advantages and disadvantages[22]. For example, the use of paper or online contact diary is inaccurate for recording contacts of short duration, which are often forgotten by respondents[16,47,54,57]. On the other hand, proximity sensor devices can address this problem quite well. However, these devices only record contacts among people equipped with such devices; thus, it seems impractical to employ these devices in a large study population. The use of PDA seems to place more burden on study participants

compared with a paper diary given that it necessitates them to input information about their contacts in an electronic device instead of just jotting down contacts in a paper diary[48]. In addition, this device may be difficult for those who are not familiar with the use of electronic devices. To date, comparison of the social mixing behavior captured by these data collection tools was only conducted in convenience surveys with small sample sizes[16,47,48,54,57].

Self-reporting on paper or online diaries is the most commonly employed method in social contact surveys. Contact data collected by the self-report method were more complete compared with contact data collected by CATI because the former offers respondents more time to remember all contacts they made during a study period[58]. The use of the CATI method is primarily motivated by the cost-efficiency of the survey, allowing recruitment of a large and geographically well-defined population sample. However, one main disadvantage of a telephone interview lies in the fact that the duration of the telephone interview is probably too long given the complexity associated with verbal recall and repetitiveness for a diary type questionnaire, resulting in incomplete or missing information[49]. Perhaps, this is a main challenge that resulted in only two surveys using this method. Face-to-face interviews can help reduce inconsistencies of information provided by respondents in the presence of trained interviewers. In addition, this method also had a good response rate compared with other methods; however, the fieldwork and data collection are costly and time consuming[36,37,42]. To date, one study has compared contact behaviors collected by the self-report mode and face-to-face interview[3].

The definition of a potentially infectious contact is of crucial importance given that it will be used as a surrogate for exposure to disease and help estimate transmission parameters[13]. Brankston et al.[62] listed 4 modes of transmission of respiratory infections: direct contact, droplet, airborne and fomite or indirect contact. Direct contact and droplet require susceptible individuals to have close contact with infected individuals to enable infection, whereas airborne and fomite transmission do not[28]. Consequently, contact definitions in most surveys did not capture potential risks from the latter transmission modes[28]. Even for droplet transmission, the use of a face-to-face conversation definition to record non-physical contacts might lead to underreporting potentially infectious events given that susceptible individuals are likely able to contract a respiratory infection by just standing or sitting next to infected individuals who are sneezing, coughing, talking, etc. with no need to exchange words. Furthermore, it seems even more challenging to record common touching frequency of shared material objects, such as door knobs, water taps, public transport support poles, etc., for which two people do not need to be in each other's physical proximity to be able to infect one another indirectly. Indeed, the more details on potentially infectious events we attempt to collect, the greater the burden we impose on respondents.

It is tempting to ask study participants to report their contacts as long as possible to obtain a broader view of contact patterns and gain insights in day-to-day variation. Nevertheless, the demanding and tedious task of diary keeping may prevent many participants from recording the information for a long time in prospective studies[63]. Beraud et al.[11] demonstrated that participants reported 6% [1%-10%] less contacts on the second day of the survey. In addition, the more contacts they reported on the first day, the larger the proportional decrease in contacts on the second day. This finding might explain why only a few surveys asked respondents to report their contacts for a duration of more than 3 days[3,15,22,27,28,43]. For ret-

rospective studies, a longer reporting period implies a longer recall period, with an associated larger bias. Therefore, in retrospective studies, researchers should try not to overstretch the reporting period.

The review provides information on the most relevant determinants of social contacts identified in previous studies. When designing future surveys, it is important to consider which characteristics may be sufficiently relevant to include as determinants. Asking study participants to report too many characteristics of contactees imposes a burden on participants. For example, collecting age of the participants and their contacts is informative, as some studies revealed that using age-related mixing patterns helped explain observed serological and infection patterns of infectious diseases like pertussis, varicella and parvovirus-B19[3,64,65]. In addition, collecting information about location, duration and frequency of contacts is also very essential for exploring mixing patterns of individuals and helping form effective strategies for disease prevention and control. Also, for school-aged children, a dominant number of contacts are made in school, leading to an indication that school closure can have a substantial impact on the spread of a respiratory infection[18,21,66–68]. When considering the duration and frequency of contact, it seems reasonable that a short random encounter of two persons is less likely to transmit a certain infectious disease compared with a more frequent encounter that lasts several hours. Accordingly, if all contacts are treated equally, it may lead to an overestimation of the individual transmission probability in cases of short, less frequent contacts and an underestimation in cases of long, more frequent contacts[27]. Several studies found that close contacts with a duration of at least 15 minutes involving skin-to-skin touching were most predictive of the pre-vaccination prevalence of Varicella Zoster Virus[64,69]. Therefore, age of the contactee and duration emerge as the most important information and should always be recorded in social contact surveys.

A comparison among all surveys based on a quantity such as the average number of contacts can be problematic. The sample serves as the first obstacle. Given different research questions or participant availability, not all the samples studied can be considered as representative of the envisaged population. This notion is important especially because age is a relevant determinant of social contacts, and samples in which a specific age class is over-represented regardless of study design can induce a strong bias on the number of contacts measured. For example, the study reporting the largest number of contacts (70.3[21]) was performed in a secondary school in the UK with the aim of estimating the reduction in social contacts due to school closure. Once these caveats are taken into account, Table 1 can be valuable to help identify all of the surveys sharing similar features that are relevant in addressing a specific research question. For example, the POLYMOD survey[4] demonstrated that the main structure of social interaction among age categories was the same among several EU countries although the strength of the interaction could vary between countries. On the other hand, the average number of contacts measured in sub-Saharan countries by Dodd[39] is considerably reduced compared with the average for high-income countries. In fact the development level can be important in determining social interactions, for example, due to local population density or reduced school attendance[41,42,69]. Quantifying the impact of different demographical factors on social contacts would require re-analysis of the datasets on the same basis and goes beyond the scope of this review. However, this re-analysis could be performed in the future as datasets of social contact surveys will be made available from researchers in a unified format[70].

This review used PubMed and Web of Knowledge for searching publications, possibly resulting in the omission of relevant publications that can be captured from other online databases, e.g. Scopus or Embase. However, the availability and accessibility of PubMed and Web of Knowledge are of great value given that anyone can easily search for and refer to relevant articles that were used and cited in this review paper. In addition, the literature research step allowed us to recover more articles independently of a specific database, possibly recovering the ones we lost querying only PubMed and Web of Knowledge. We were exclusively interested in social contact surveys using the contact diary method, leading to the exclusion of a large number of surveys that exclusively employed direct observation or proximity sensor methods to measure contact behavior of individuals. The use of these methods along with their advantages and disadvantages have been summarized elsewhere[5,63]. Third, to the best of our knowledge, our search query omitted the relevant articles of Leecaster et al.[57] and Kwok et al.[71], which are eligible for this review. These articles are missing the survey/questionnaire/diary word in the abstract and title and therefore elude our searching method. The recent publication date (2016 and 2018) also prevented these articles from appearing in the references of the relevant articles.

Since the POLYMOD survey, there has been an increasing trend in the number of social contact surveys used to collect empirical contact data. Social contact surveys have been conducted widely in many countries, but most focused on high-income countries. These surveys used a range of different study designs with different study subjects, settings, sampling scheme to study designs, data collection tools and data collection methods. Moreover, the definition of "contact" and its characteristics also differ, making comparison of contact patterns among surveys even more difficult. Improvements towards a unified definition of "contact" and standard practice in data collection could help increase the quality of collected data, leading to more robust and reliable conclusions about contact patterns of individuals.

This review demonstrates that contact surveys typically have in the order of a thousand participants, rely on convenience sampling, and use a retrospective design with paper diaries and self-reporting of contacts over a single day. Major determinants for this number of contactees include characteristics of the respondent (age, gender, and health status), time (weekday or weekend, and term time or holiday) and their immediate environment (household size and urban versus rural). A typical number of different contactees reported per day is in the order of 20 for country wide studies, a quantity that proved remarkably robust despite the many different study designs.

# Supporting information

**S1 File. The comprehensive table of all social contact surveys.**

**S1 Fig. The average samples.** Average sample size of surveys in general population and surveys in specific setting.

**S2 Fig. Sampling schemes by continents and periods.**

**S3 Fig. Sampling schemes in details.**

**S4 Fig. Distribution of social contact surveys by study designs.**

**S5 Fig. Average number of contacts by factors.** Average number of contacts measured and 95% CI in weekday vs weekend (a), holiday vs. term-time (b), well vs unwell health status (c) and during vs outside flu season (d). For surveys reporting mean number and standard deviation a 95% CI for the mean has been computed.

**S6 Fig. Median of number of contacts among surveys.** Median and quantiles of contacts. Surveys are labeled according to the publication's first author, year and the country in which the survey was performed.

**S7 Fig. Global map of social contact surveys.**

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# Author Contributions

TVH, PC, PB and NH conceived and designed the inclusion criteria. TVH and PC performed the screening. TVH, PC and NH wrote a first draft of the paper. TVH, PC, AM, JW, CG, PB and NH contributed to the final version of the paper. All authors read and approved the final manuscript.

# References

[1] Roy M Anderson, Robert M May, and B Anderson. *Infectious diseases of humans: dynamics and control*, volume 28. Wiley Online Library, 1992.

[2] W John Edmunds, CJ O'callaghan, and DJ Nokes. Who mixes with whom? a method to determine the contact patterns of adults that may lead to the spread of airborne infections. *Proceedings of the Royal Society of London B: Biological Sciences*, 264(1384):949–957, 1997.

[3] Jacco Wallinga, Peter Teunis, and Mirjam Kretzschmar. Using data on social contacts to estimate age-specific transmission parameters for respiratory-spread infectious agents. *American journal of epidemiology*, 164(10):936–944, 2006.

[4] Joël Mossong, Niel Hens, Mark Jit, Philippe Beutels, Kari Auranen, Rafael Mikolajczyk, Marco Massari, Stefania Salmaso, Gianpaolo Scalia Tomba, Jacco Wallinga, et al. Social contacts and mixing patterns relevant to the spread of infectious diseases. *PLoS medicine*, 5(3):e74, 2008.

[5] JM Read, WJ Edmunds, S Riley, J Lessler, and DAT Cummings. Close encounters of the infectious kind: methods to measure social mixing behaviour. *Epidemiology & Infection*, 140(12):2117–2130, 2012.

[6] David Moher, Alessandro Liberati, Jennifer Tetzlaff, Douglas G Altman, Prisma Group, et al. Preferred reporting items for systematic reviews and meta-analyses: the prisma statement. *PLoS medicine*, 6(7):e1000097, 2009.

[7] Endnote, a smarter way to research. `http://www.endnote.com`, 2016.

[8] Philipp Beutels, Ziv Shkedy, Marc Aerts, and Pierre Van Damme. Social mixing patterns for transmission models of close contact infections: exploring self-evaluation and diary-based data collection through a web-based interface. *Epidemiology & Infection*, 134(6):1158–1166, 2006.

[9] Mart L Stein, Peter GM van der Heijden, Vincent Buskens, Jim E van Steenbergen, Linus Bengtsson, Carl E Koppeschaar, Anna Thorson, and Mirjam EE Kretzschmar. Tracking social contact networks with online respondent-driven detection: who recruits whom? *BMC infectious diseases*, 15(1):522, 2015.

[10] Lander Willem, Kim Van Kerckhove, Dennis L Chao, Niel Hens, and Philippe Beutels. A nice day for an infection? weather conditions and social contact patterns relevant to influenza transmission. *PloS one*, 7(11):e48695, 2012.

[11] Guillaume Béraud, Sabine Kazmercziak, Philippe Beutels, Daniel Levy-Bruhl, Xavier Lenne, Nathalie Mielcarek, Yazdan Yazdanpanah, Pierre-Yves Boëlle, Niel Hens, and Benoit Dervaux. The french connection: the first large population-based contact survey in france relevant for the spread of infectious diseases. *PloS one*, 10(7):e0133203, 2015.

[12] Nathanael Lapidus, Xavier De Lamballerie, Nicolas Salez, Michel Setbon, Rosemary M Delabre, Pascal Ferrari, Nanikaly Moyen, Marie-Lise Gougeon, Frédéric Vely, Marianne Leruez-Ville, et al. Factors associated with post-seasonal serological titer and risk factors for infection with the pandemic a/h1n1 virus in the french general population. *PloS one*, 8(4):e60127, 2013.

[13] Helen Bernard, Richela Fischer, Rafael T Mikolajczyk, Mirjam Kretzschmar, and Manfred Wildner. Nurses contacts and potential for infectious disease transmission. *Emerging infectious diseases*, 15(9):1438, 2009.

[14] RT Mikolajczyk, MK Akmatov, S Rastin, and Mirjam Kretzschmar. Social contacts of school children and the transmission of respiratory-spread pathogens. *Epidemiology & Infection*, 136(6):813–822, 2008.

[15] Rafael T Mikolajczyk and Mirjam Kretzschmar. Collecting social contact data in the context of disease transmission: prospective and retrospective study designs. *Social Networks*, 30(2):127–135, 2008.

[16] Timo Smieszek, Stefanie Castell, Alain Barrat, Ciro Cattuto, Peter J White, and Gérard Krause. Contact diaries versus wearable proximity sensors in measuring contact patterns at a conference: method comparison and participants attitudes. *BMC infectious diseases*, 16(1):341, 2016.

[17] WJ Edmunds, G Kafatos, J Wallinga, and JR Mossong. Mixing patterns and the spread of close-contact infectious diseases. *Emerging themes in epidemiology*, 3(1):10, 2006.

[18] KT Eames, NL Tilston, PJ White, E Adams, and WJ Edmunds. The impact of illness and the impact of school closure on social contact patterns. *Health technology assessment (Winchester, England)*, 14(34):267–312, 2010.

[19] Ken TD Eames, Natasha L Tilston, and W John Edmunds. The impact of school holidays on the social mixing patterns of school children. *Epidemics*, 3(2):103–108, 2011.

[20] Ken TD Eames, Natasha L Tilston, Ellen Brooks-Pollock, and W John Edmunds. Measured dynamic social contact patterns explain the spread of h1n1v influenza. *PLoS computational biology*, 8(3):e1002425, 2012.

[21] Charlotte Jackson, Punam Mangtani, Emilia Vynnycky, Katherine Fielding, Aileen Kitching, Huda Mohamed, Anita Roche, and Helen Maguire. School closures and student contact patterns. *Emerging infectious diseases*, 17(2):245, 2011.

[22] Jonathan M Read, Ken TD Eames, and W John Edmunds. Dynamic social networks and the implications for the spread of infectious disease. *Journal of The Royal Society Interface*, 5(26):1001–1007, 2008.

[23] Albert Jan van Hoek, Nick Andrews, Helen Campbell, Gayatri Amirthalingam, W John Edmunds, and Elizabeth Miller. The social life of infants in the context of infectious disease transmission; social contacts and mixing patterns of the very young. *PloS one*, 8(10):e76180, 2013.

[24] Leon Danon, Thomas A House, Jonathan M Read, and Matt J Keeling. Social encounter networks: collective properties and disease transmission. *Journal of The Royal Society Interface*, page rsif20120357, 2012.

[25] Leon Danon, Jonathan M Read, Thomas A House, Matthew C Vernon, and Matt J Keeling. Social encounter networks: characterizing great britain. In *Proc. R. Soc. B*, volume 280, page 20131037. The Royal Society, 2013.

[26] Magnus Strömgren, Einar Holm, Örjan Dahlström, Joakim Ekberg, Henrik Eriksson, Armin Spreco, and Toomas Timpka. Place-based social contact and mixing: a typology of generic meeting places of relevance for infectious disease transmission. *Epidemiology & Infection*, pages 1–12, 2017.

[27] Timo Smieszek. A mechanistic model of infection: why duration and intensity of contacts should be included in models of disease spread. *Theoretical Biology and Medical Modelling*, 6(1):25, 2009.

[28] Timo Smieszek, Elena U Burri, Robert Scherzinger, and Roland W Scholz. Collecting close-contact social mixing data with contact diaries: reporting errors and biases. *Epidemiology & Infection*, 140(4):744–752, 2012.

[29] Mart L Stein, Jim E Van Steenbergen, Vincent Buskens, Peter GM Van Der Heijden, Charnchudhi Chanyasanha, Mathuros Tipayamongkholgul, Anna E Thorson, Linus Bengtsson, Xin Lu, and Mirjam EE Kretzschmar. Comparison of contact patterns relevant for transmission of respiratory pathogens in thailand and the netherlands using respondent-driven sampling. *PLoS One*, 9(11):e113711, 2014.

[30] Jan van de Kassteele, Jan van Eijkeren, Jacco Wallinga, et al. Efficient estimation of age-specific social contact rates between men and women. *The Annals of Applied Statistics*, 11(1):320–339, 2017.

[31] Marco Ajelli and Maria Litvinova. Estimating contact patterns relevant to the spread of infectious diseases in russia. *Journal of Theoretical Biology*, 419:1–7, 2017.

[32] Kin O Kwok, Benjamin J Cowling, Vivian WI Wei, Kendra M Wu, Jonathan M Read, Justin Lessler, Derek A Cummings, JS Malik Peiris, and Steven Riley. Social contacts and the locations in which they occur as risk factors for influenza infection. *Proceedings of the Royal Society of London B: Biological Sciences*, 281(1789):20140709, 2014.

[33] Jonathan M Read, Justin Lessler, Steven Riley, Shuying Wang, Li Jiu Tan, Kin On Kwok, Yi Guan, Chao Qiang Jiang, and Derek AT Cummings. Social mixing patterns in rural and urban areas of southern china. *Proceedings of the Royal Society of London B: Biological Sciences*, 281(1785):20140268, 2014.

[34] Kathy Leung, Mark Jit, Eric HY Lau, and Joseph T Wu. Social contact patterns relevant to the spread of respiratory infectious diseases in hong kong. *Scientific reports*, 7(1):7974, 2017.

[35] Yoko Ibuka, Yasushi Ohkusa, Tamie Sugawara, Gretchen B Chapman, Dan Yamin, Katherine E Atkins, Kiyosu Taniguchi, Nobuhiko Okabe, and Alison P Galvani. Social contacts, vaccination decisions and influenza in japan. *J Epidemiol Community Health*, pages jech–2015, 2015.

[36] Yang-chih Fu, Da-Wei Wang, and Jen-Hsiang Chuang. Representative contact diaries for modeling the spread of infectious diseases in taiwan. *PLoS One*, 7(10):e45113, 2012.

[37] Peter Horby, Pham Quang Thai, Niel Hens, Nguyen Thi Thu Yen, Dang Dinh Thoang, Nguyen Manh Linh, Nguyen Thu Huong, Neal Alexander, W John Edmunds, Tran Nhu Duong, et al. Social contact patterns in vietnam and implications for the control of infectious diseases. *PloS one*, 6(2):e16965, 2011.

[38] Moses Chapa Kiti, Timothy Muiruri Kinyanjui, Dorothy Chelagat Koech, Patrick Kiio Munywoki, Graham Francis Medley, and David James Nokes. Quantifying age-related rates of social contact using diaries in a rural coastal population of kenya. *PloS one*, 9(8):e104786, 2014.

[39] Peter J Dodd, Clare Looker, Ian D Plumb, Virginia Bond, Ab Schaap, Kwame Shanaube, Monde Muyoyeta, Emilia Vynnycky, Peter Godfrey-Faussett, Elizabeth L Corbett, et al. Age-and sex-specific social contact patterns and incidence of mycobacterium tuberculosis infection. *American journal of epidemiology*, 183(2):156–166, 2015.

[40] Simon P Johnstone-Robertson, Daniella Mark, Carl Morrow, Keren Middelkoop, Melika Chiswell, Lisa DH Aquino, Linda-Gail Bekker, and Robin Wood. Social mixing patterns within a south african township community: implications for respiratory disease transmission and control. *American journal of epidemiology*, 174(11):1246–1255, 2011.

[41] Alessia Melegaro, Emanuele Del Fava, Piero Poletti, Stefano Merler, Constance Nyamukapa, John Williams, Simon Gregson, and Piero Manfredi. Social contact structures and time use patterns in the manicaland province of zimbabwe. *PloS one*, 12(1):e0170459, 2017.

[42] Carlos G Grijalva, Nele Goeyvaerts, Hector Verastegui, Kathryn M Edwards, Ana I Gil, Claudio F Lanata, Niel Hens, et al. A household-based study of contact networks relevant for the spread of infectious diseases in the highlands of peru. *PloS one*, 10(3):e0118457, 2015.

[43] Allison E Aiello, Amanda M Simanek, Marisa C Eisenberg, Alison R Walsh, Brian Davis, Erik Volz, Caroline Cheng, Jeanette J Rainey, Amra Uzicanin, Hongjiang Gao, et al. Design and methods of a social network isolation study for reducing respiratory infection transmission: The ex-flu cluster randomized trial. *Epidemics*, 15:38–55, 2016.

[44] Laura M Glass and Robert J Glass. Social contact networks for the spread of pandemic influenza in children and teenagers. *BMC public health*, 8(1):61, 2008.

[45] F DeStefano, M Haber, D Currivan, T Farris, B Burrus, B Stone-Wiggins, A McCalla, H Guled, H Shih, P Edelson, et al. Factors associated with social contacts in four communities during the 2007–2008 influenza season. *Epidemiology & Infection*, 139(8):1181–1190, 2011.

[46] Gail E Potter, Mark S Handcock, Ira M Longini Jr, and M Elizabeth Halloran. Estimating within-school contact networks to understand influenza transmission. *The annals of applied statistics*, 6(1):1, 2012.

[47] Timo Smieszek, Victoria C Barclay, Indulaxmi Seeni, Jeanette J Rainey, Hongjiang Gao,

Amra Uzicanin, and Marcel Salathé. How should social mixing be measured: comparing web-based survey and sensor-based methods. *BMC infectious diseases*, 14(1):136, 2014.

[48] James M McCaw, Kristian Forbes, Paula M Nathan, Philippa E Pattison, Garry L Robins, Terence M Nolan, and Jodie McVernon. Comparison of three methods for ascertainment of contact information relevant to respiratory pathogen transmission in encounter networks. *BMC infectious diseases*, 10(1):166, 2010.

[49] David A Rolls, Nicholas L Geard, Deborah J Warr, Paula M Nathan, Garry L Robins, Philippa E Pattison, James M McCaw, and Jodie McVernon. Social encounter profiles of greater melbourne residents, by location–a telephone survey. *BMC infectious diseases*, 15(1):494, 2015.

[50] Patricia Therese Campbell, Jodie McVernon, Niraj Shrestha, Paula M Nathan, and Nicholas Geard. Who's holding the baby? a prospective diary study of the contact patterns of mothers with an infant. *BMC infectious diseases*, 17(1):634, 2017.

[51] Szu-Chieh Chen, Shu-Han You, Min-Pei Ling, Chia-Pin Chio, and Chung-Min Liao. Use of seasonal influenza virus titer and respiratory symptom score to estimate effective human contact rates. *Journal of epidemiology*, 22(4):353–363, 2012.

[52] S-C Chen and Z-S You. Social contact patterns of school-age children in taiwan: comparison of the term time and holiday periods. *Epidemiology & Infection*, 143(6):1139–1147, 2015.

[53] Dih-Ling Luh, Zhi-Shin You, and Szu-Chieh Chen. Comparison of the social contact patterns among school-age children in specific seasons, locations, and times. *Epidemics*, 14:36–44, 2016.

[54] Rossana Mastrandrea, Julie Fournet, and Alain Barrat. Contact patterns in a high school: a comparison between data collected using wearable sensors, contact diaries and friendship surveys. *PloS one*, 10(9):e0136497, 2015.

[55] Mart L Stein, Jim E Van Steenbergen, Charnchudhi Chanyasanha, Mathuros Tipayamongkholgul, Vincent Buskens, Peter GM van der Heijden, Wasamon Sabaiwan, Linus Bengtsson, Xin Lu, Anna E Thorson, et al. Online respondent-driven sampling for studying contact patterns relevant for the spread of close-contact pathogens: a pilot study in thailand. *PloS one*, 9(1):e85256, 2014.

[56] Ilker Etikan, Sulaiman Abubakar Musa, and Rukayya Sunusi Alkassim. Comparison of convenience sampling and purposive sampling. *American Journal of Theoretical and Applied Statistics*, 5(1):1–4, 2016.

[57] Molly Leecaster, Damon JA Toth, Warren BP Pettey, Jeanette J Rainey, Hongjiang Gao, Amra Uzicanin, and Matthew Samore. Estimates of social contact in a middle school based on self-report and wireless sensor data. *PloS one*, 11(4):e0153690, 2016.

[58] O Akakzia, V Friedrichs, WJ Edmunds, and J Mossony. Comparison of paper diary vs computer assisted telephone interview for collecting social contact data relevant to the spread of airborne infectious diseases. In *EUROPEAN JOURNAL OF PUBLIC HEALTH*, volume 17, pages 189–189. OXFORD UNIV PRESS GREAT CLARENDON ST, OXFORD OX2 6DP, ENGLAND, 2007.

[59] Qiaohong Liao, Tian Bai, Lei Zhou, Sirenda Vong, Junqiao Guo, Wei Lv, Libo Dong, Nijuan Xiang, Zi Li, Yang Huai, et al. Seroprevalence of antibodies to highly pathogenic avian influenza a (h5n1) virus among close contacts exposed to h5n1 cases, china, 2005–2008. *PloS one*, 8(8):e71765, 2013.

[60] Niel Hens, Girma Minalu Ayele, Nele Goeyvaerts, Marc Aerts, Joel Mossong, John W Edmunds, and Philippe Beutels. Estimating the impact of school closure on social mixing

behaviour and the transmission of close contact infections in eight european countries. *BMC infectious diseases*, 9(1):187, 2009.

[61] Sample size calculator, 2016.

[62] Gabrielle Brankston, Leah Gitterman, Zahir Hirji, Camille Lemieux, and Michael Gardam. Transmission of influenza a in human beings. *The Lancet infectious diseases*, 7(4):257–265, 2007.

[63] Yang-chih Fu. Contact diaries: Building archives of actual and comprehensive personal networks. *Field methods*, 19(2):194–217, 2007.

[64] Nele Goeyvaerts, Niel Hens, Benson Ogunjimi, Marc Aerts, Ziv Shkedy, Pierre Van Damme, and Philippe Beutels. Estimating infectious disease parameters from data on social contacts and serological status. *Journal of the Royal Statistical Society: Series C (Applied Statistics)*, 59(2):255–277, 2010.

[65] Mirjam Kretzschmar, Peter FM Teunis, and Richard G Pebody. Incidence and reproduction numbers of pertussis: estimates from serological and social contact data in five european countries. *PLoS medicine*, 7(6):e1000291, 2010.

[66] Niel Hens, Nele Goeyvaerts, Marc Aerts, Ziv Shkedy, Pierre Van Damme, and Philippe Beutels. Mining social mixing patterns for infectious disease models based on a two-day population survey in belgium. *BMC infectious diseases*, 9(1):5, 2009.

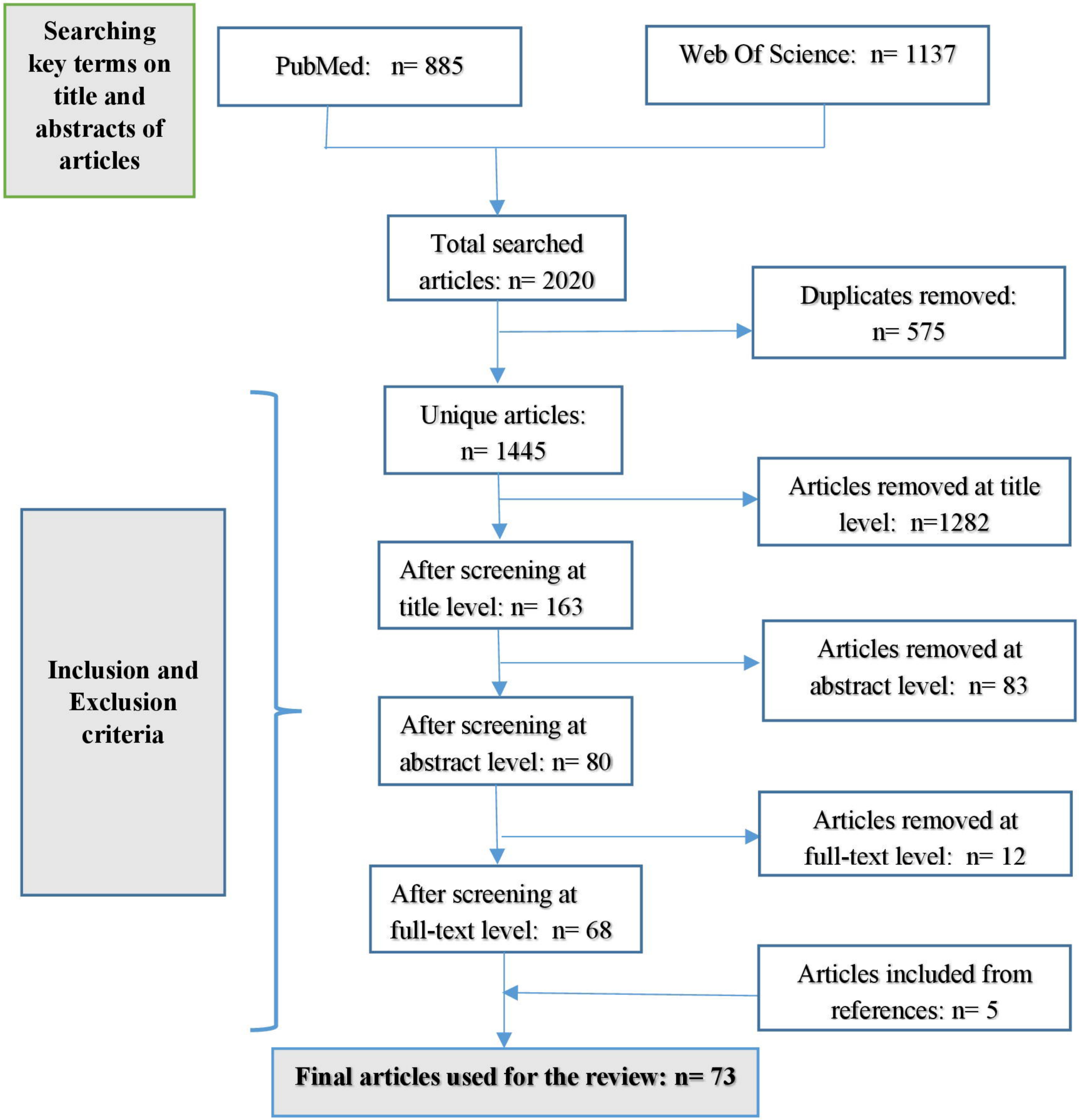
[67] Tianyou Zhang, Xiuju Fu, Chee Keong Kwoh, Gaoxi Xiao, Limsoon Wong, Stefan Ma, Harold Soh, Gary Kee Khoon Lee, Terence Hung, and Michael Lees. Temporal factors in school closure policy for mitigating the spread of influenza. *Journal of public health policy*, 32(2):180–197, 2011.

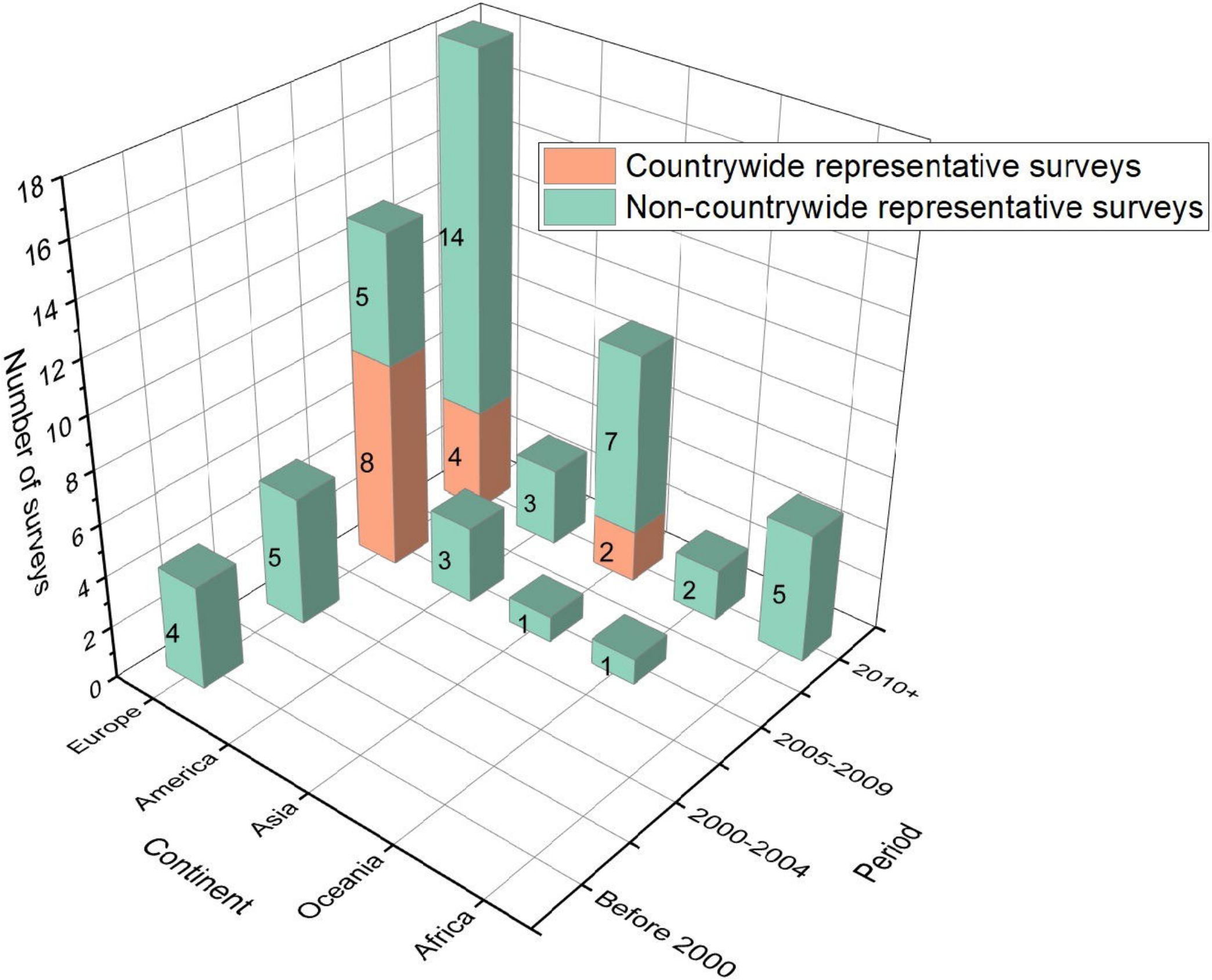
[68] Giancarlo De Luca, Kim Van Kerckhove, Pietro Coletti, Chiara Poletto, Nathalie Bossuyt, Niel Hens, and Vittoria Colizza. The impact of regular school closure on seasonal influenza epidemics: a data-driven spatial transmission model for belgium. *BMC Infectious Diseases*, 18(1):29, Jan 2018.

[69] Alessia Melegaro, Mark Jit, Nigel Gay, Emilio Zagheni, and W John Edmunds. What types of contacts are important for the spread of infections? using contact survey data to explore european mixing patterns. *Epidemics*, 3(3):143–151, 2011.

[70] TransMid. data repository, 2017.

[71] Kin On Kwok, Ben Cowling, Vivian Wei, Steven Riley, and Jonathan M Read. Temporal variation of human encounters and the number of locations in which they occur: A longitudinal study of hong kong residents. *Journal of The Royal Society Interface*, 15(138):20170838, 2018.


Searching key terms on title and abstracts of articles
PubMed: n= 885
Web Of Science: n= 1137
Total searched articles: n= 2020
Duplicates removed: n= 575
Unique articles: n= 1445
Articles removed at title level: n=1282
After screening at title level: n= 163
Articles removed at abstract level: n= 83
After screening at abstract level: n= 80
Articles removed at full-text level: n= 12
After screening at full-text level: n= 68
Articles included from references: n= 5
Inclusion and Exclusion criteria
Final articles used for the review: n= 73


Countrywide representative surveys
Non-countrywide representative surveys
Number of surveys
0
2
4
6
8
10
12
14
16
18
Continent
Europe
America
Asia
Oceania
Africa
Period
Before 2000
2000-2004
2005-2009
2010+
4
5
8
5
14
4
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3
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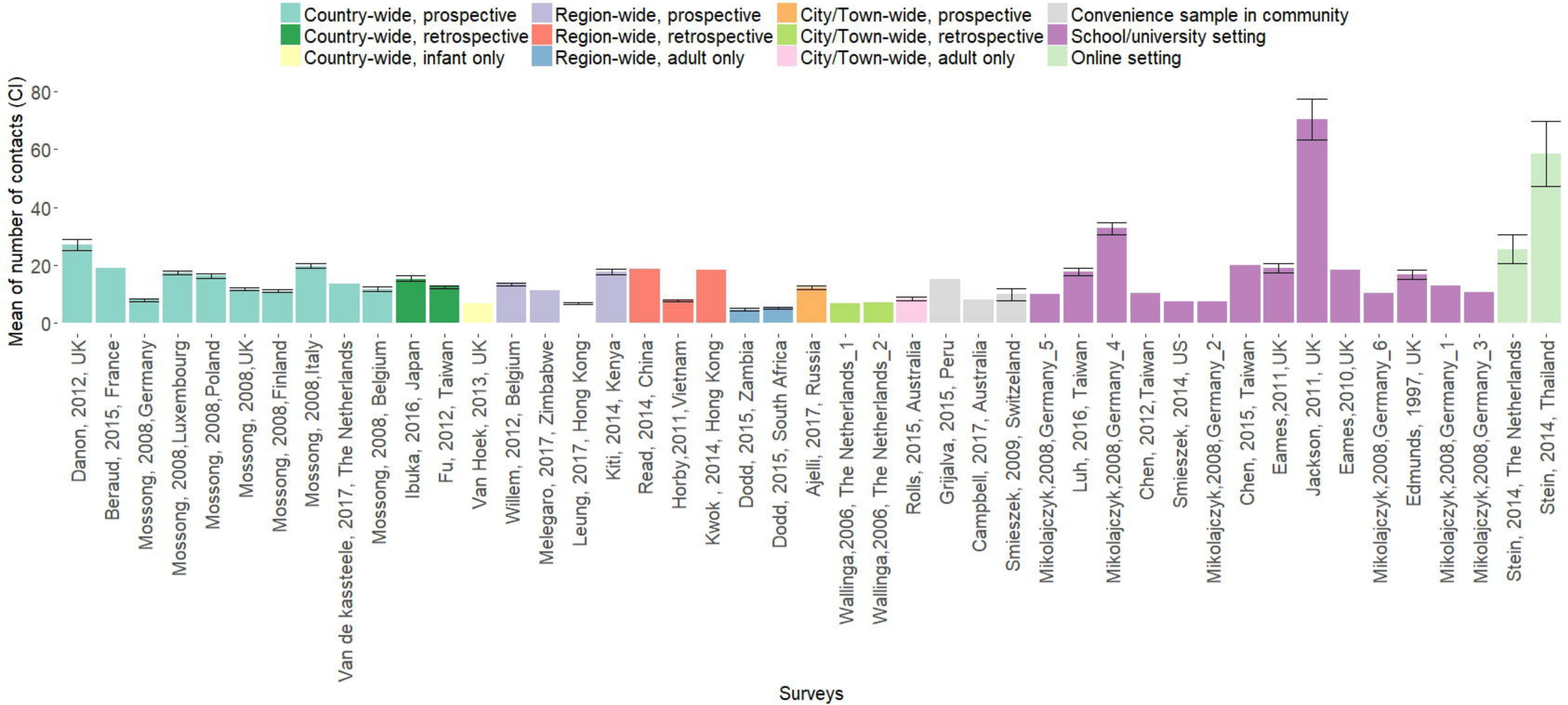
Country-wide, prospective
Country-wide, retrospective
Country-wide, infant only
Region-wide, prospective
Region-wide, retrospective
Region-wide, adult only
City/Town-wide, prospective
City/Town-wide, retrospective
City/Town-wide, adult only
Convenience sample in community
School/university setting
Online setting
Mean of number of contacts (CI)
0
20
40
60
80
Danon, 2012, UK
Beraud, 2015, France
Mossong, 2008,Germany
Mossong, 2008,Luxembourg
Mossong, 2008,Poland
Mossong, 2008,UK
Mossong, 2008,Finland
Mossong, 2008,Italy
Van de kassteele, 2017, The Netherlands
Mossong, 2008, Belgium
Ibuka, 2016, Japan
Fu, 2012, Taiwan
Van Hoek, 2013, UK
Willem, 2012, Belgium
Melegaro, 2017, Zimbabwe
Leung, 2017, Hong Kong
Kiti, 2014, Kenya
Read, 2014, China
Horby,2011,Vietnam
Kwok , 2014, Hong Kong
Dodd, 2015, Zambia
Dodd, 2015, South Africa
Ajelli, 2017, Russia
Wallinga,2006, The Netherlands_1
Wallinga,2006, The Netherlands_2
Rolls, 2015, Australia
Grijalva, 2015, Peru
Campbell, 2017, Australia
Smieszek, 2009, Switzeland
Mikolajczyk,2008,Germany_5
Luh, 2016, Taiwan
Mikolajczyk,2008,Germany_4
Chen, 2012,Taiwan
Smieszek, 2014, US
Mikolajczyk,2008,Germany_2
Chen, 2015, Taiwan
Eames,2011,UK
Jackson, 2011, UK
Eames,2010,UK
Mikolajczyk,2008,Germany_6
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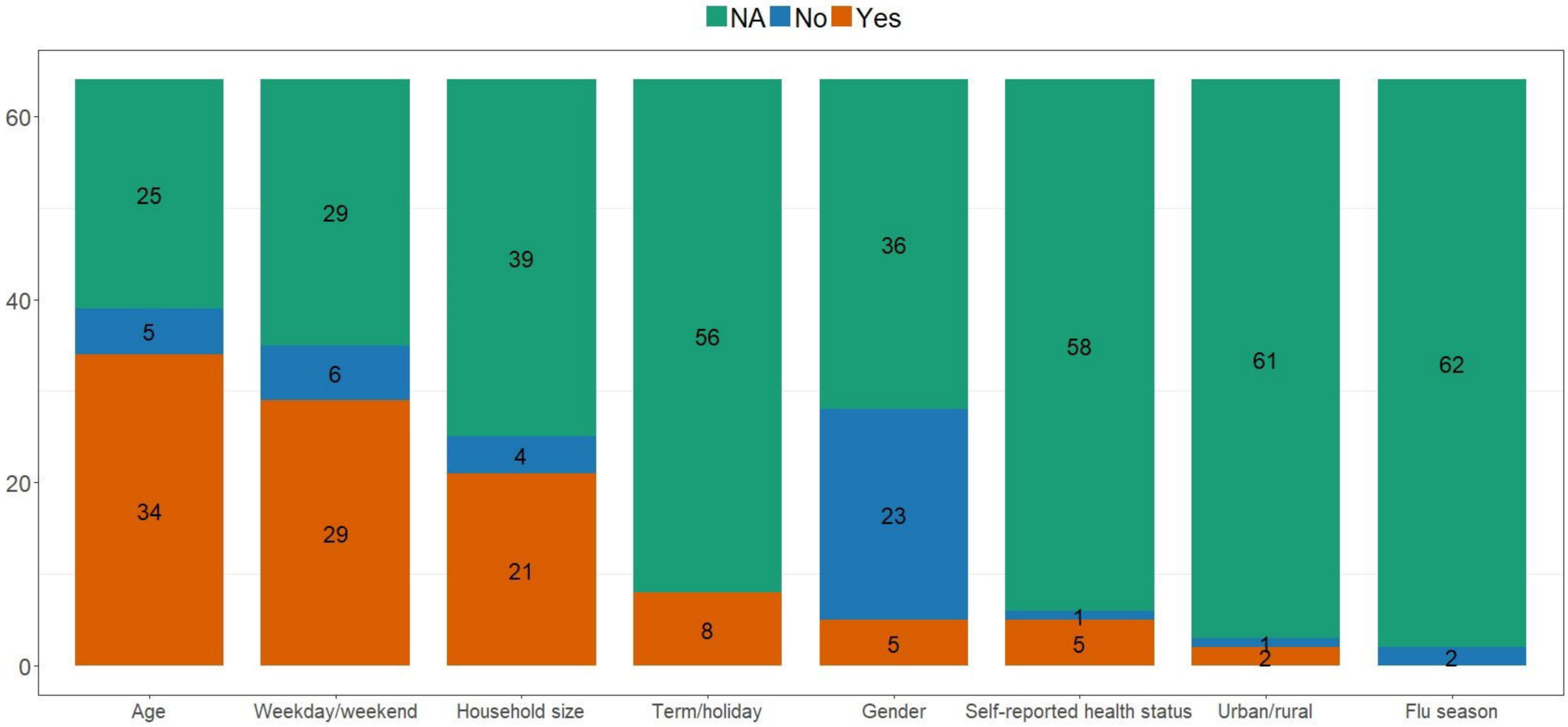
Stein, 2014, Thailand
Surveys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No
Yes
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23
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58
1
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61
1
2
62
2
Age
Weekday/weekend
Household size
Term/holiday
Gender
Self-reported health status
Urban/rural
Flu season