The impact of illness and the impact of school closure on social contact patterns

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Abstract

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Background: Mathematical models, based on data describing normal patterns of social mixing, are used to understand epidemics in order to predict patterns of disease spread and plan interventions and responses. However, individuals who are ill show behavioural changes that affect their social mixing patterns and predictive models should take into account these changes if they are to be effective.
Objectives: To describe and quantify the changes in (1) social contact behaviour experienced by individuals when they are ill with pandemic H1N1 influenza (swine flu) and (2) mixing patterns of school children that take place as a result of swine flu-related school closures.
Methods: For the first part of the study, a self-completed questionnaire-based study was carried out in the autumn/winter of 2009–10. The study population was individuals who had been diagnosed with swine flu and who received a swine flu antiviral prescription from an antiviral distribution centre (ADC). It consisted of an initial survey to be filled in when participants were symptomatic with swine flu and a follow-up survey to be filled in when they had recovered. Each part of the questionnaire had two sections: patient details and a contact diary. The second part of the study was adapted to quantify the difference in mixing patterns of pupils between the school term and the half-term holiday as school closures did not occur during the study period. Eight schools participated and questionnaire packs were distributed to them, containing two surveys: one to be filled in during the school term and one during the spring half-term holiday.
Results: For the patient study, approximately 3800 surveys were distributed by 31 ADCs. Overall, 317 responses to the initial survey were received and 179 participants returned the follow-up survey. For all types of a contact, except contacts made at home, there were highly significant differences in contact behaviour (Wilcoxon signed-rank test, $p < 0.001$). Individuals made substantially fewer contacts when they were ill than when they were well. Analysis showed that returning to work was the most significant predictor of increased numbers of contacts. Also, the greater the change in the number of symptoms reported, the greater the change in the number of contacts. For the school study, approximately 1100 questionnaire packs were distributed and 134 responses were received, with 119 paired contact diaries. Pupils reported on average 18.51 contacts each day during term time and 9.24 during the half-term holiday – a reduction of over 50% and a highly significant change (Wilcoxon signed-rank test, $p < 0.0001$).
Conclusions: The evidence from this study suggests that ill individuals make substantial changes to their social contact patterns. These changes are strongly linked to absence from work and the severity of the reported illness. Epidemiological modellers should therefore consider the implications of illness-related behavioural changes on model predictions. Future studies to measure the extent of behavioural change in a broader cross-section of infected cases could be valuable, along with more detailed studies of the social contact patterns of school children, focusing on differences between school terms and school holidays.

Contents

List of abbreviations

ADC	antiviral distribution centre
IQR	interquartile range
NPFS	National Pandemic Flu Service
SD	standard deviation

All abbreviations that have been used in this report are listed here unless the abbreviation is well known (e.g. NHS), or it has been used only once, or it is a non-standard abbreviation used only in figures/tables/appendices, in which case the abbreviation is defined in the figure legend or in the notes at the end of the table.

Executive summary

Background

Mathematical models are increasingly used to understand epidemics, to predict future patterns of disease spread, and to plan interventions and responses. Models of epidemic spread rely heavily on the assumptions that they make about patterns of mixing within the population of interest. In recent years, high-quality data have been collected to describe 'normal' patterns of social mixing. However, while such data give good information about healthy individuals, they tell us very little about the behaviour of individuals when they are ill. If, as seems likely, there are significant behavioural changes that take place as a result of illness – such as taking time off work or avoiding social gatherings – we would expect changes in mixing patterns; for predictive models to be effective, they should take into account these changes.

Objectives

- To describe and quantify the changes in social contact behaviour experienced by individuals when they are ill with pandemic H1N1 influenza (swine flu).
- To describe and quantify the changes in mixing patterns of school children that take place as a result of school closures.

Methods

A self-completed questionnaire-based study was designed and carried out in the autumn/winter of 2009–10. The study population was individuals who had been diagnosed with swine flu and who received a swine flu antiviral prescription from an antiviral distribution centre (ADC). The study aimed to quantify changes in participants' social contact behaviour.

The study consisted of two parts: the *initial survey* was designed to be filled in when participants were symptomatic with swine flu; the *follow-up survey* was designed to be filled in once they had recovered. Each part was returned by post in a provided prepaid envelope.

Each part of the questionnaire had two sections.

The first section collected information about the participant (age, sex, household size and composition), their health status (symptoms list, a measure of their current health, date of symptom onset, antiviral use), their behaviour (work/school/college attendance, public transport use), and the impact of their illness on their activities (time off work, receiving care from others). This section also asked participants for their name and address so that the follow-up survey could be sent to them.

The second section was a contact diary in which participants were asked to list all the people they met over the course of a day. A meeting was defined as 'either talking face-to-face or skin-to-skin contact (e.g. a handshake, a kiss, contact sports)'. Participants were asked to give some information about each person whom they reported meeting:

- age (or age range)
- gender
- whether there was skin-to-skin contact (such contacts will be referred to as 'physical' contacts below)
- how long the encounter lasted (participants were asked to tick one of the following: under 5 minutes, 5–10 minutes, 10 minutes to 1 hour, 1–4 hours, over 4 hours)
- where the encounter occurred (participants were asked to tick one or more of the following: home, work/school/college, travel, leisure activity, other)
- how often they normally met this person (participants were asked to tick one of the following: daily or almost daily, once or twice weekly, once or twice monthly, less than monthly, never met before).

Contact diaries contained space for details of 33 contacts to be recorded. Participants were asked whether they had included everyone whom they met during the day and, if not, were asked how many 'additional' people they met.

The follow-up survey was posted to participants approximately 2 weeks after they completed and returned the initial survey; it was hoped that this time interval would be long enough that most participants would have recovered and resumed their normal activities, but not so long that they would have lost interest in taking part. Those individuals who had not returned their follow-up survey within a further 2 weeks were sent a reminder. Survey forms were coded with a unique identification number that allowed us to match up an individual's initial and follow-up surveys.

The intention was that each participant would record their social contact behaviour once when they were ill with swine flu and once when they had recovered.

A covering letter explaining the purpose of the study and instructions for filling in the forms was included with each survey.

The initial survey was distributed along with antiviral prescriptions at antiviral distribution centres (ADCs) in all parts of England.

Approximately 3800 surveys were distributed by 31 ADCs. Overall, 317 responses to the initial survey were received, and, of these, participants, 179 also returned the follow-up survey.

It was intended that a similar study should take place to look at the impact of swine flu-related school closure on the social contact patterns of school children. However, as swine flu related closures did not occur during the autumn of 2009, this study could not take place. Instead, the methodology was adapted to attempt to quantify the difference in mixing patterns between the school term and the half-term holiday.
Eight schools were recruited to take part, and approximately 1100 questionnaire packs were distributed, containing two surveys similar to those described above: one to be filled in during the school term and one during the spring half-term holiday. A total of 134 responses were received, with 119 completed contact diaries.

Results

Swine flu antiviral patient study

We explored changes in each participant's reported contact data. Because of the repeated sampling of participants, we have paired data (i.e. two completed contact diaries) from each participant.

The completed contact diaries contained a great deal of detail about contact behaviour, and there was therefore a multitude of different comparisons that could be attempted; for the sake of simplicity and clarity we restricted ourselves to the following key measures:

- *all* number of contacts listed on the contact diary
- *all plus additional* contacts listed on the contact diary plus any 'additional' contacts
- *physical* total number of physical (skin-to-skin) contacts reported
- *home* total number of home contacts recorded
- *work* total number of work/school/college contacts recorded
- *other* total number of contacts recorded in travel/leisure/other settings
- *long duration* total number of contacts recorded that lasted over 1 hour
- *short duration* total number of contacts recorded that lasted less than 10 minutes
- *frequent* total number of contacts recorded who were encountered once a week or more
- *infrequent* total number of contacts recorded who were encountered less than once a month.

In each case, we sought to explore the extent to which the numbers of these different types of social contacts differed between the initial and the follow-up surveys.

There were indeed noticeable changes in contact behaviour, although contacts taking place at home did not vary. For all types of a contact, except contacts made at home, the differences are highly significant (Wilcoxon signed-rank test, $p < 0.001$). There was no significant change in the number of home contacts.

However, when viewing the sample, and whichever measure of contact we used, we could see that individuals made substantially fewer contacts when they were ill than when they were well. Contacts made by ill participants tended to take place at home (with very few in the workplace or in other settings); they were generally with people whom they met often and for long periods of time, and they often included physical contact.

We postulated that changes in social mixing patterns would be associated with age, gender, changes in health status, returning to work/school/college, household size, and change in day of the week (for instance, from weekday to weekend or vice versa).

These factors were analysed using a linear regression model. Several factors emerge as significant: returning to work/school/college, change in number of symptoms, age and household size.

Returning to work/school/college was associated with a large increased change in the number of contacts reported, being a significant factor in the change in all-plus-additional contacts ($p < 0.001$), all contacts ($p < 0.001$), frequent contacts ($p < 0.001$), long-duration contacts ($p = 0.003$), short-duration contacts ($p = 0.007$), contacts in 'other settings' ($p = 0.013$) and (unsurprisingly) work/school/college contacts ($p < 0.001$).

The change in the number of symptoms reported was also associated with an increased change in numbers of social contacts, being a significant factor in the change in all contacts ($p = 0.022$), infrequent contacts ($p < 0.001$), physical contacts ($p = 0.015$) and short contacts ($p = 0.007$).

Older age was associated with a reduced change in number of contacts: younger adults reported a larger change in their number of infrequent contacts ($p = 0.041$), whereas older adults reported a smaller change in their number of physical contacts ($p = 0.017$ for ages 45–59, $p = 0.034$ for ages over 60) and long-duration contacts ($p = 0.006$ for ages 30–44, $p = 0.002$ for ages 45–59, $p = 0.045$ for ages over 60).

A larger household was associated with a smaller change in the number of infrequent contacts ($p = 0.041$) and physical contacts ($p = 0.032$).

Being infected with diagnosed swine flu had a considerable impact on the social contact patterns of those who participated in our study. Infected participants generally took time away from work/school/college and from social activities, and therefore made considerably fewer contacts when they were ill than when they had recovered. Participants made approximately two-thirds fewer contacts when they were unwell.

The distribution of social contacts changed when people were unwell; unwell people made approximately two-thirds of their social contacts at home, falling to one-quarter when they had recovered, although the reported absolute number of contacts made at home stayed almost constant. Not surprisingly, work/school/college contacts and contacts made in other settings (travel, leisure, other) fell dramatically when people were ill.

There was an observed tendency for the more transient contacts (infrequent contacts and contacts not involving physical contact) to be more influenced by illness than stronger contacts (frequent contacts and physical contacts). This again is unsurprising, as stronger contacts are more likely to be made in the home.

The analysis made clear the important role played by the workplace (or school, or college) on social contacts – returning to work was by some distance the most significant predictor of increased numbers of contacts.

The seriousness of infection also played a role; the greater the change in the number of symptoms reported, the greater the change in the number of contacts.

Differences between age groups emerged, with those in younger age groups tending to have a greater change in their contact patterns; this can be explained by the differences in social mixing patterns between schools and workplaces, with older individuals appearing to mingle in smaller groups than younger individuals.

School closure

A similar paired survey carried out in schools to compare mixing patterns during the half-term holiday with those during school term observed large changes in social contact behaviour. Pupils who completed the survey reported, on average, 18.51 contacts each day during term time and 9.24 during the half-term holiday – a reduction of over 50%. The change in number of contacts was highly significant (Wilcoxon signed-rank test, $p < 0.0001$).

Conclusions

The evidence from this study suggests that ill individuals make substantial changes to their social contact patterns. Participants in the study made substantially fewer social contacts when they were ill compared with when they had recovered. The changes in contact patterns were strongly linked to absence from work and the severity of the reported illness, with age and household size also playing a role. Epidemiological modellers should therefore be wary of using data about 'normal' contact patterns to parameterise mathematical models of disease spread, and should consider the implications of illness-related behavioural changes on model predictions.

This study highlights areas for future research. First, a more detailed study that aims to recruit a representative sample of cases would be particularly valuable; the study here, owing to its sampling methodology and the time constraints under which it took place, almost certainly ended up with a sample population that was experiencing relatively severe symptoms. Although such people are of interest, they are likely to display greater behavioural change than the average infected case. It would be of value to carry out studies, perhaps during forthcoming seasonal flu seasons, which measure the extent of behavioural change in a broader cross-section of infected cases.

Second, as it was clear that children played a dominant role in the swine flu pandemic, and that they might be expected to do so in future pandemics, and as it was apparent from the UK incidence data that normal patterns of school holidays had a significant impact on transmission, we advocate more detailed studies of the social contact patterns of school children, particularly focusing on differences between school terms and school holidays. Our experience is that for school-based studies to be successful the researcher must be prepared to make a substantial investment of time and energy – such studies are therefore best conceived as long-term projects achieving high levels of engagement with participating schools, rather than as rapid exercises.

Chapter 1
Introduction

The spread of infectious diseases is, in many cases, determined by patterns of mixing between individuals in a population. In the case of human-to-human transmission, social contact behaviour is the key to understanding the dynamics of a wide range of common infections, such as measles, influenza and the common cold.[1–15] The response to the 2009 H1N1 influenza (termed swine flu throughout) pandemic illustrated the requirement for well-parameterised mathematical models of the spread of infection.[5,9,16–17] Governments required modellers to provide guidance on likely scenarios, to aid planning and to give advice on vaccination strategies.[3,18–19] Over recent years, more and more research has been devoted to measuring and understanding human social contact patterns. Studies have ranged from detailed analyses of social networks within contained communities[8,20–22] and small-scale detailed surveys,[23] to large-scale population-based surveys of mixing patterns.[4,15,24] The most notable such study (POLYMOD), involving over 7000 individuals across Europe, consisted of self-completed contact diaries in which participants noted details of all the individuals with whom they came into contact over the course of a day.[15] The POLYMOD study allowed a quantitative comparison of contacts made, say, at home and at work, or of long- and short-duration contacts; it also allowed more complex quantities to be evaluated, such as the fraction of contacts made at home that lasted over 1 hour, and included skin-to-skin contact.

As a representation of normal social behaviour, the POLYMOD study is unsurpassed and its results have already been used to parameterise numerous models of infectious disease spread.[3,7,10,13,18] The flaw is that this and other studies are designed to measure only 'normal' behaviour; while this gives us important information, it does not tell us all that we need to know – in particular, it gives us little information about the behaviour of infectious individuals. If, as seems certain, social contact behaviour changes when we are sick, then models based on normal behaviour are in danger of reaching the wrong conclusions. Furthermore, ad hoc attempts to correct this by, for instance, assuming a halving of contacts when ill, are fraught with danger. Would home contacts and work contacts fall by the same amount? Would ill people reduce their interactions with people they normally meet only occasionally to the same extent as those with people whom they normally meet every day?

To shed light on these issues, therefore, in the study described here we aimed to measure changes in social contact behaviour that took place as a result of illness. Using methodology similar to that developed in the POLYMOD study,[15] participants completed contact diaries to describe their contact patterns over the course of a day. In our study, however, participants completed two separate contact diaries: one when they were unwell and one when they had recovered.

The study took place during the 2009–10 swine flu pandemic. This new variant of influenza was first identified in April 2009 in the Americas, and was soon introduced into the UK.[3,19,25] Originally appearing as sporadic cases associated with travel to Mexico and the USA, swine flu soon established itself in the UK, with large numbers of cases occurring in July 2009.[3,25] Antiviral medication was made available in the UK to those with probable/suspected swine flu. Initially, prescriptions were generally issued by GPs, but in mid-July a telephone- and internet-based system [the National Pandemic Flu Service (NPFS)] was launched, whereby reporting a list of symptoms allowed individuals to be issued with an antiviral prescription. Ill individuals were encouraged to seek the assistance of a 'flu friend' to collect their prescription for them.

Cases were concentrated in children, and incidence fell once schools closed for their summer break.[25–31] However, it was expected, and indeed it came to pass, that a second wave of cases would be seen in the autumn once schools reopened.

In order to measure changes in social contact behaviour that took place as a result of illness, a questionnaire-based study was designed and carried out in the UK in autumn/winter 2009.

A second study was carried out to measure changes in school children's contact behaviour as a result of school closure.

Chapter 2
Methods

Survey design

The questionnaire had two parts; the *initial survey* was designed to be filled in when participants were symptomatic with suspected swine flu; the *follow-up survey* was designed to be filled in once they had recovered. Each part was returned in a provided prepaid envelope.

Each part of the questionnaire had two sections: the first section collected information about the participant (age, sex, household size and composition), their health status (symptoms list, a measure of their current health, a measure of their health on the day that they were most unwell, date of symptom onset, antiviral use), their behaviour (work/school/college attendance, public transport use) and the impact of their illness on their activities (time off work, receiving care from others). This section also asked participants for their name and address so that the follow-up survey could be sent to them.

The second section was a contact diary in which participants were asked to list all of the people they met over the course of a day. A meeting was defined as 'either talking face-to-face or skin to skin contact (e.g. a handshake, a kiss, contact sports)'. Participants were asked to give some information about each person whom they reported meeting:

- age (or age range)
- gender
- whether there was skin-to-skin contact (such contacts will be referred to as 'physical' contacts below)
- how long the encounter lasted (participants were asked to tick one of the following: under 5 minutes, 5–10 minutes, 10 minutes to 1 hour, 1–4 hours, over 4 hours)
- where the encounter occurred (participants were asked to tick one or more of the following: home, work/school/college, travel, leisure activity, other)
- how often they normally met this person (participants were asked to tick one of the following: daily or almost daily, once or twice weekly, once or twice monthly, less than monthly, never met before).

There was sufficient space on the contact diary to give this information about 33 different contacts. Participants were asked whether they had included everyone they met during the day and, if not, they were asked how many other people they met that day; these will be termed 'additional contacts'.

The follow-up survey was posted to participants approximately 2 weeks after they completed and returned the initial survey; it was hoped that this time interval would be long enough to ensure that most participants would have recovered and resumed their normal activities, but not so long that they would have lost interest in taking part. Those participants who had not returned their follow-up survey within a further 2 weeks were sent a reminder. Survey forms were coded with a unique identification number that allowed us to match up an individual's initial and follow-up surveys.

The intention was that each participant would record their social contact behaviour once when they were ill with swine flu and once when they had recovered.

A covering letter explaining the purpose of the study and instructions for filling in the forms was included with each survey. All questionnaire forms can be found in Appendix 1.

The study received ethical approval from the Riverside Research Ethics Committee.

It was intended that a similar study would be undertaken to measure the impact of swine flu-related school closures on the contact patterns of school pupils.[5,10–11,14] However, contrary to expectations, such closures did not occur in autumn 2009. Nevertheless, a small 'half-term' study was carried out in February/March 2010 – see Appendix 2 for further details.

Participant recruitment

Participants were recruited to the study through antiviral distribution centres (ADCs). ADCs (generally pharmacies) were sampled via a stratified random sampling design, in which two ADCs in each region of England were selected from a list of all ADCs. This allowed us to access individuals with probable swine flu and to achieve a wide geographical spread. It became apparent that many of the sampled ADCs were small and were handling very few cases by the time the survey was under way. Hence, it was decided to supplement the initial sample, by additionally sampling from among the busiest ADCs in each of the sampled regions. This resulted in a total of 31 ADCs being sampled. Questionnaire packs were distributed by ADCs along with antiviral prescriptions. Because of the abnormally heavy workload that these ADCs were experiencing, in many cases, due to the epidemic, and to reduce the demands placed on pharmacy staff, ADCs were not asked to screen potential participants (which would, in any case, have been made difficult by the fact that in many instances prescriptions were collected not by the potential participants themselves but on their behalf by their 'flu friend'). No age restrictions were applied to participation; however, it was suggested in the covering letter that if the individual receiving antiviral medicine was under 16 years of age, then their parent/guardian might prefer to complete the survey on their behalf.

Each questionnaire pack contained a covering letter, instructions for filling in the forms, and the initial survey itself.

On the basis of a power calculation, using a conservative estimate of the expected change in number of social contacts (based on data collected in the POLYMOD study[15]) it was hoped to recruit 800 participants into the study.

Analysis

A database was designed using EPIDATA 3.1, and data entry was carried out in March 2010, once all initial and follow-up surveys had been received.

Analyses were carried out to test whether changes in number of contacts took place, and to explore factors influencing the size of any such changes. Change in number of contacts was defined as 'number of contacts reported in the follow-up survey minus number of contacts reported in the initial survey', where 'contacts' could refer to a number of different measures of interactions – such as contacts at home, or contacts involving skin-to-skin contact.

To test whether the number of contacts changed, a non-parametric Wilcoxon signed-rank test was used. A backwards stepwise linear regression model was used to explore significant contributory factors, the factor with the largest non-significant p-value being removed at each step and the model rerun until all remaining factors were significant ($p < 0.05$).

Statistical analyses were carried out using STATA 11.

Capping contacts

A few participants used the 'additional contacts' section of the contact diary to report that they had contact with many hundreds of people in a day (for instance, by working as teachers or in a busy shop); to avoid skewed results generated by such outliers a cap of 33 contacts (the number of rows on the contact diary) was applied to contacts listed, and a cap of 66 was applied to the total number of contacts (i.e. all listed on the contact diary plus the number reported as additional contacts).

The application of this cap affected only a small number of contact diaries (the option of reporting numbers of additional contacts without needing to record extra details about each of these contacts was not required by most participants – it was used three times in the initial contact diary and 12 times in the follow-up contact diary) and does not qualitatively alter our conclusions.

Study population

Participating ADCs

During mid-October 2009, 31 ADCs were recruited to take part in the study, distributing questionnaire packs along with antiviral prescriptions. Depending on their size, ADCs were given between 25 and 300 questionnaire packs to distribute, with some requesting additional packs.

In total, 4265 questionnaire packs were sent to ADCs, of which approximately 3795 were distributed along with antiviral prescriptions. Distribution of questionnaire packs by ADCs began on the 10 November 2009 and continued until approximately 9 January 2010. Details of the spatial distribution of ADCs can be found in *Table 1*.

Participants

Overall, 317 initial surveys were returned and 308 follow-up surveys were sent out (nine participants did not provide an address). A total of 179 follow-up surveys were eventually returned (45 of which

TABLE 1 *Spatial distribution of the study sample and response rate*[a]

Region	ADCs recruited	Approximate no. of questionnaires distributed	Initial response (rate) (*n*, %)	Follow-up response (rate) (*n*, %)
East of England	5	566	46 (8.1)	30 (65.2)
East Midlands	1	200	5 (2.5)	2 (40.0)
London	2	300	19 (6.3)	11 (57.9)
North East	3	619	73 (11.8)	34 (46.8)
North West	3	350	16 (4.6)	10 (62.5)
South East Coast	3	200	14 (7.0)	9 (64.3)
South Central	3	412	45 (10.9)	26 (57.8)
South West	4	252	32 (12.7)	20 (62.5)
West Midlands	4	384	41 (10.7)	22 (53.7)
Yorkshire and the Humber	3	512	26 (5.1)	15 (57.7)
Total	*31*	*3795*	*317 (8.4)*	*179 (56.5)*

a Follow-up surveys were issued to only those who returned the initial survey; the follow-up response rate is therefore defined as the fraction of initial respondents who also returned a follow-up survey.

had received a reminder). The interval between completing the initial and the follow-up surveys had a median of 19 days and an interquartile range (IQR) of 14 to 30 days. The overall response rate was disappointingly low – see below for further discussion (see Chapter 4 – Discussion). The rest of this report will describe the results provided by these 179 participants, which will be referred to as the 'study population'.

The spatial distribution of participating ADCs and of participants is shown in *Table 1*. In some cases, participating ADCs were unable to confirm exactly how many initial surveys they distributed; in such cases we have assumed that all of the initial surveys that were sent to them were given out.

Population characteristics

The study population was not evenly split by gender (40.2% male, 59.8% female). The median age of the study population was 47 (IQR 27 to 56). The demographic characteristics of the sample are shown in *Table 2*. Within our sample, young adults are under-represented and older adults over-represented. It is not possible to calculate the response rates from different groups. Also included in *Table 2* are the characteristics of those individuals who returned the initial survey but not the follow-up survey; those returning only the initial survey tend to be younger and to live in larger households.

TABLE 2 *Study population demographic summary*[a]

	Completed initial survey only (*n* = 138)	Completed both surveys (*n* = 179)	UK population
Female (%)	62.9	59.8	50.9
Age 0–14 (%)	20.6	16.8	17.5
Age 15–29 (%)	22.8	11.2	20.0
Age 30–44 (%)	24.3	17.9	21.1
Age 45–69 (%)	20.6	34.6	19.2
Age ≥ 60 (%)	11.8	19.6	22.1
Mean household size	3.1	2.7	2.4

a Including those who completed only the initial survey and those who completed both the initial and the follow-up survey (UK population characteristics included for comparison).

Within our sample of interest (those who returned both surveys), 117 (65%) reported that they would normally attend work/school/college on the day of their initial survey, while 22 (12%) respondents reported that they would normally use public transport on the day of their initial survey.

The mean household size in the study population was 2.7, with a median of 2 and an IQR of 2 to 4. As might be expected by the observed age distribution of the sample, a large fraction of households contained only one or two people.

Chapter 3
Results

Describing infection – initial survey

As anticipated, the vast majority [169 (94.4%)] of the study population reported that they were unwell with swine flu on the day that they completed the initial questionnaire. Ill individuals were asked to report which symptoms they had from a list of 14 possibilities. The fraction of individuals reporting each symptom is shown in *Figure 1*. On average, ill individuals reported 7.8 symptoms. Tiredness, cough, headache, fever and blocked/runny nose were the most common symptoms, being reported by over 70% of respondents.

Individuals were also asked to record how ill they felt, on a scale of 0–10, with 0 being the 'worst imaginable health state' and 10 the 'best imaginable health state'. The distribution of initial health states of those individuals who reported that they were unwell with swine flu when they completed the initial survey is shown in *Figure 2*. The mean reported health state was 3.38 [standard deviation (SD 1.66)]. For comparison, those individuals who completed only the initial survey had a mean reported health state of 3.61 (SD 1.95) – these two sets of reported health states were not significantly different.

The mean reported health state of individuals on the day that they felt most ill was 1.98 (SD 1.23).

Describing recovery – comparing initial and follow-up questionnaires

Of those 169 individuals who were unwell with swine flu when they completed the initial questionnaire, 146 (86.4%) had recovered by the time they filled in the follow-up questionnaire. The median duration of infection of those who had recovered was 9 days (IQR 6 to 14 days), and 32 (21.9%) of participants reported that they were ill for over a fortnight.

As anticipated, there were large changes in health state between the initial and follow-up survey reports of those who reported that they were no longer unwell when they completed the follow-up survey (*Figure 3*). We see, in most cases, that

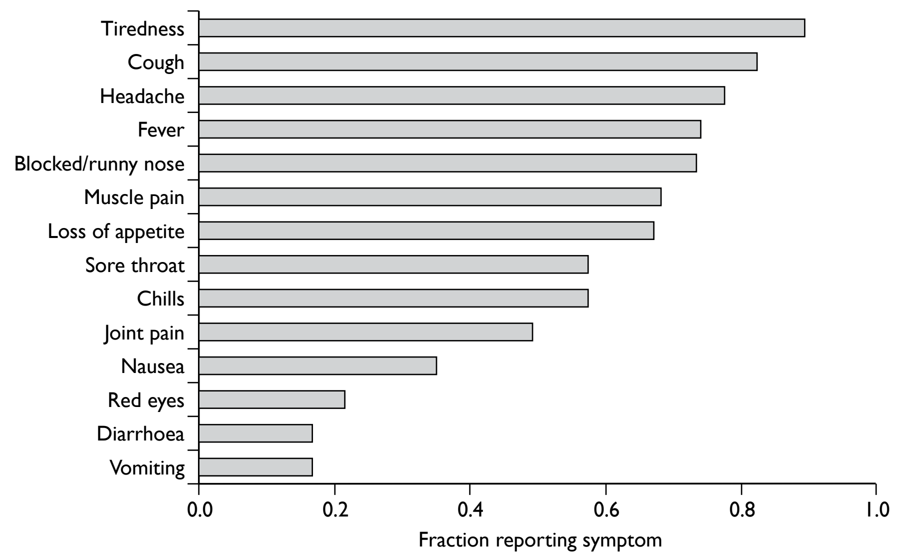

FIGURE 1 *Fraction of individuals reporting each symptom from the symptoms list.*

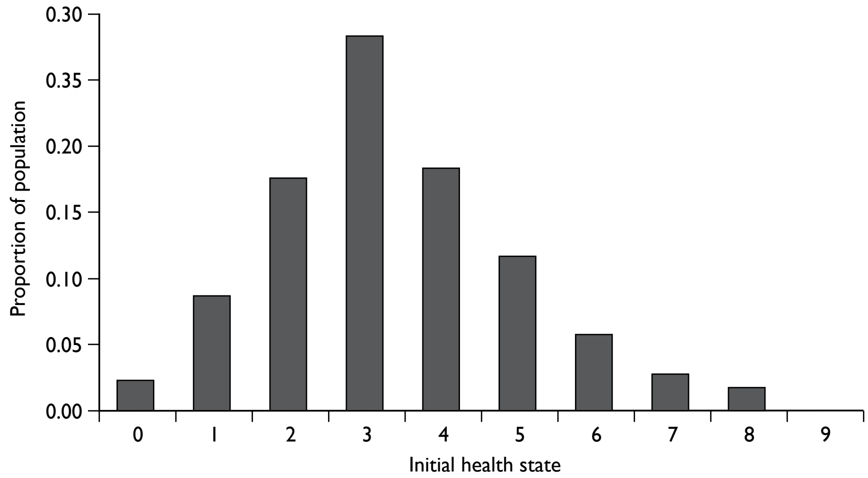

***FIGURE 2** Distribution of initial health states reported by individuals unwell with swine flu (measured on a scale of 0 – the 'worst imaginable health state' – to 10 – the 'best imaginable health state').*

participants reported a substantial change in their health state (mean change 4.92, SD 1.83, $p < 0.001$, one-sample t-test).

Participants were asked whether they took time off work/school/college/child-care group/social activities because of their illness; 74.1% of the 162 participants who answered reported that they did take time off. The median length of time off was 6 days (IQR 4 to 8 days) and six (5.0%) respondents reported that they took over a fortnight away from work/school/college/child-care group/social activities.

Overall, 59 individuals (33.0%) reported that they did not attend work/school/college on the day that they completed the initial survey, but that they did attend work/school/college on the day that they completed the follow-up survey.

Contact patterns

Baseline behaviour – comparison with POLYMOD

The most extensive survey to date of normal contact patterns took place in the POLYMOD

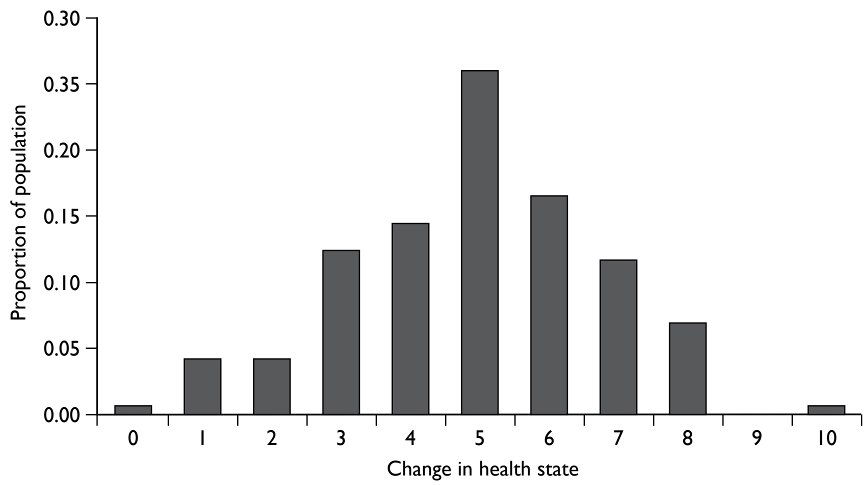

***FIGURE 3** Change in health state of people who recorded that they were unwell when they filled in the initial survey but had recovered when they filled in the follow-up survey (n = 146).*

study in 2005–6.[15] The POLYMOD study sampled 7290 people around Europe, with 1012 in the UK; POLYMOD participants completed a contact diary very similar to that applied in this project. In order to check the reasonableness of our results, we will briefly compare them with those produced by POLYMOD.

POLYMOD sampled 1012 individuals from the UK, whose responses we compare with the 155 participants in our survey who reported that they were well on the day that they completed the follow-up survey; from these 155 individuals, 144 useable contact diaries were obtained.

POLYMOD reported that respondents from the UK named a mean of 11.74 contacts (SD 7.67); our results are broadly similar, with a mean of 10.30 contacts (SD 8.51); our study found that approximately 25% of contacts took place at home, while POLYMOD reported that 23% of contacts occurred at home. Our study found that approximately 40% of contacts involved skin-to-skin contact, which is consistent with POLYMOD (in which the proportion of contacts involving skin-to-skin contact ranges from about 35% in the workplace to 75% at home; our study found that approximately 25% of work/school/college contacts and 72% of home contacts involved skin-to-skin contact). Our study reported more contacts taking place at work/school/college (47% compared with 35%).

Our study and POLYMOD are therefore in broad agreement about 'normal' social contact behaviour. Differences, such as they are, may well be explained by differences in the sample population demographics – our study population contained more older adults – but seasonal differences may also have played a part (POLYMOD took place mainly in the spring, our study in the autumn/winter).

Changes in contact behaviour

The primary aim of this study was to measure the impact of illness on contact patterns. Here, therefore, we explore changes in each participant's reported contact data. Because the methodology involved repeated sampling of participants, we have paired data (i.e. two completed contact diaries) from each participant.

The completed contact diaries contain a great deal of detail about contact behaviour, and there is therefore a multitude of different comparisons that could be attempted; for the sake of simplicity and clarity, and to avoid overanalysing a small database, we restricted ourselves to the following key measures:

- *all* number of contacts listed on the contact diary
- *all plus additional* contacts listed on the contact diary plus any 'additional' contacts
- *physical* total number of physical (skin-to-skin) contacts reported
- *home* total number of home contacts recorded
- *work* total number of work/school/college contacts recorded
- *other* total number of contacts recorded in travel/leisure/other settings
- *long duration* total number of contacts recorded that lasted over 1 hour
- *short duration* total number of contacts recorded that lasted less than 10 minutes
- *frequent* total number of contacts recorded who were encountered once a week or more
- *infrequent* total number of contacts recorded who were encountered less than once a month.

In each case, we seek to explore the extent to which the numbers of these different types of social contacts differed between the initial and the follow-up surveys.

We expected the most marked behavioural changes in those people who were unwell at the time of the initial survey and had recovered by the time of the follow-up survey. When restricting our attention to this subsample ($n = 146$), we see that there were, indeed, noticeable changes in contact behaviour (*Figure 4*), although contacts taking place at home did not vary between the initial and follow-up surveys. The differences between the initial and follow-up surveys are shown in *Table 3*. For all types of a contact except contacts made at home the differences are highly significant (Wilcoxon signed-rank test, $p < 0.001$). There was no significant change in the number of home contacts.

The bump on the right of some plots in *Figure 4* is the result of the capping of the number of contacts permitted, as described above.

Very similar patterns are seen when the sample is not restricted to those who recovered between completing the initial and the follow-up surveys (see *Figure 5* and *Table 5*, Appendix 3). The only notable difference between *Figures 4* and *5* is that, as we would expect, there are more individuals in *Figure 5* who reported no change in their contact behaviour.

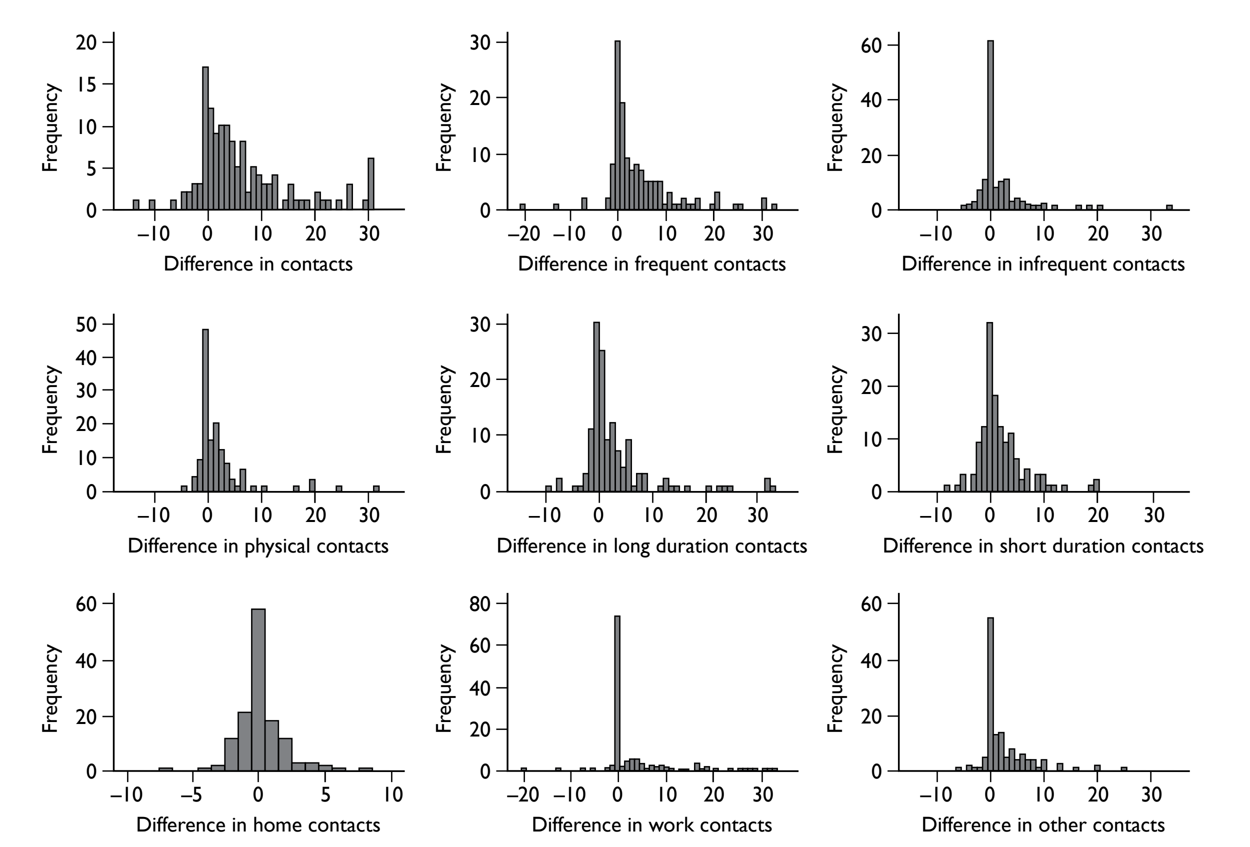

FIGURE 4 *Change in number of contacts reported in the initial and follow-up surveys by those participants who reported that they were unwell on the day of the initial survey and had recovered by the time they completed the follow-up survey; for each of the participants who completed a useable contact diary for both the initial and the follow-up survey (n = 135), the change in number of contacts of the relevant type is defined as the number recorded in the follow-up survey minus the number recorded in the initial survey.*

TABLE 3 *The number of contacts reported in the initial and follow-up surveys by those individuals who reported that they were unwell during the initial survey and recovered by the time they completed the follow-up survey*[a]

Type of contact	Initial survey (*n* = 141): mean (SD)	Follow-up survey (*n* = 138): mean (SD)	Difference (*n* = 135) Mean (SD)	Relative difference (percentage of follow-up mean)	Median (IQR)	*p*-value (median ≠ 0)
All	3.58 (3.75)	10.30 (8.51)	6.82 (9.01)	66	4 (1 to 10)	< 0.0001
All plus additional	3.58 (3.75)	12.72 (14.80)	9.30 (15.45)	73	4 (1 to 11)	< 0.0001
Frequent	2.91 (3.48)	7.33 (7.15)	4.49 (7.63)	61	2 (0 to 7)	< 0.0001
Infrequent	0.52 (0.11)	2.08 (4.42)	1.61 (4.74)	77	0 (0 to 2)	0.0003
Physical	1.77 (1.75)	4.10 (5.10)	2.36 (5.01)	58	1 (0 to 3)	< 0.0001
Long duration	2.02 (2.29)	5.42 (6.63)	3.45 (6.86)	64	1 (0 to 4)	< 0.0001
Short duration	1.01 (1.45)	2.94 (4.18)	1.99 (4.43)	68	1 (0 to 4)	< 0.0001
Home	2.38 (1.54)	2.58 (2.12)	0.19 (1.81)	7	0 (–1 to 1)	0.5317
Work/school/college	0.73 (3.35)	4.57 (7.92)	3.90 (8.39)	85	0 (0 to 5)	< 0.0001
Other	0.48 (1.16)	3.01 (4.57)	2.59 (4.62)	86	1 (0 to 4)	< 0.0001

a 'Difference' refers to the difference in the number of contacts reported by those participants who returned a contact diary for both the initial and the follow-up questionnaires (*n* = 135). Mean, SD, median and IQR of the difference are shown. The median difference is tested for significant difference from zero, and the *p*-value shown.

However we view the sample, and whichever measure of contact we use, we can see that individuals made substantially fewer contacts when they were ill than when they were well. Contacts made by ill participants tended to take place at home (with very few in the workplace or in other settings); they were generally with people whom they met often and for long periods of time and they often included physical contact.

The distribution of social contacts changed when people were unwell; unwell people made approximately two-thirds of their social contacts at home, falling to one-quarter when they had recovered, although the reported absolute number of contacts made at home stayed almost constant. Not surprisingly, work/school/college contacts and contacts made in other settings (travel, leisure, other) fell dramatically when people were ill.

We note, for comparison, that individuals who completed only the initial survey reported 3.98 contacts on average when they were ill (SD 3.90); this is not significantly different from the number of contacts reported in the initial survey by those who completed both the initial and the follow-up survey (two sample *t*-test, $p = 0.58$).

We postulated that changes in social mixing patterns may be associated with age, gender, health status, attendance at work/school/college, household size and public transport use. However, because very few participants (6.7%) reported that their public transport use differed between the two questionnaires we exclude considerations of public transport use from the analysis that follows.

An initial simple regression analysis was carried out, suggesting that the following factors might have an influence on the observed changes in contact patterns:

- age group (reference group: age 0–14)
- gender
- returning to work/school/college

***TABLE 4** Regression analysis results for factors related to changes in number of contacts reported by those individuals who reported that they were unwell during the initial survey and recovered by the time they completed the follow-up survey, and who returned a completed contact diary from both the initial and the follow-up survey (n = 135)[a]*

Contact type	Factor	Coefficient	95% confidence interval	*p*-value	r^2
All plus additional	Returning to work	11.00	5.91 to 16.09	<0.001	0.15
All	Returning to work	8.12	5.27 to 10.98	<0.001	0.24
	Change in no. of symptoms	0.70	0.10 to 1.29	0.022	
Frequent	Returning to work	6.76	4.31 to 9.21	<0.001	0.18
Infrequent	Change in no. of symptoms	0.66	0.33 to 1.00	<0.001	0.10
	House size	–0.57	–1.12 to –0.02	0.041	
	Age 15–29	2.05	0.09 to 4.02	0.041	
Physical	House size	–0.96	–1.84 to –0.08	0.032	0.13
	Change in no. of symptoms	0.47	0.09 to 0.84	0.015	
	Age 45–59	–3.21	–5.83 to –0.59	0.017	
	Age over 60	–3.46	–6.65 to –0.27	0.034	
Long duration	Returning to work	3.70	1.32 to 6.07	0.003	0.15
	Age 30–44	–4.85	–8.29 to –1.42	0.006	
	Age 45–59	–4.96	–8.10 to –1.81	0.002	
	Age over 60	–3.92	–7.75 to –0.08	0.045	
Short duration	Returning to work	2.06	0.56 to 3.56	0.007	0.10
	Change in no. of symptoms	0.43	0.12 to 0.75	0.007	
Home	No significant factors				
Work	Returning to work	9.09	6.55 to 11.63	<0.001	0.27
Other	Returning to work	–2.04	–3.64 to –0.44	0.013	0.05

a Analysis includes only factors with *p*-value < 0.05. 'Work' should be interpreted as covering work, school and college.

- change in health (measured as a binary unwell/well, or as change in number of symptoms reported, or as change in self-assessed health status recorded on a 10-point scale)
- household size (the number of people in the participant's household, not including the participant)
- change in day of the week (from weekday to weekend or vice versa).

These factors were included in a backwards, stepwise regression model, with the factor with the largest non-significant p-value being removed at each step and the model rerun until all remaining factors were significant ($p < 0.05$). Results are shown in *Table 4*. The data set contains a small number of outliers, and therefore the confidence intervals should be treated with caution.

As we can see, although there is a great deal of variation that is not explained by the model, several factors emerge as significant: returning to work/school/college, change in number of symptoms, age and household size.

Returning to work/school/college was associated with a large increased change in the number of contacts reported, being a significant factor in the change in all-plus-additional contacts ($p < 0.001$), all contacts ($p < 0.001$), frequent contacts ($p < 0.001$), long-duration contacts ($p = 0.003$), short-duration contacts ($p = 0.007$), contacts in 'other settings' ($p = 0.013$) and (unsurprisingly) work/school/college contacts ($p < 0.001$).

The change in the number of symptoms reported was also associated with an increased change in numbers of social contacts, being a significant factor in the change in all contacts ($p = 0.022$), infrequent contacts ($p < 0.001$), physical contacts ($p = 0.015$) and short contacts ($p = 0.007$).

Older age was associated with a reduced change in number of contacts: younger adults reported a larger change in their number of infrequent contacts ($p = 0.041$), whereas older adults reported a smaller change in their number of physical contacts ($p = 0.017$ for ages 45–59, $p = 0.034$ for ages over 60) and long-duration contacts ($p = 0.006$ for ages 30–44, $p = 0.002$ for ages 45–59, $p = 0.045$ for ages over 60).

A larger household was associated with a smaller change in the number of infrequent contacts ($p = 0.041$) and physical contacts ($p = 0.032$).

School closure

A similar paired survey carried out in schools to compare mixing patterns during the half-term holiday with those during school term observed large changes in social contact behaviour (see Appendix 2 for further details). Pupils who completed the survey reported, on average, 18.51 contacts ('All' contacts, in the terminology above) each day during term time and 9.24 during the half-term holiday, a reduction of over 50%. The change in number of contacts was highly significant (Wilcoxon signed-rank test, $p < 0.0001$).

Chapter 4
Discussion

Being infected with diagnosed swine flu had a considerable impact on the social contact patterns of those who participated in the study. Infected participants generally took time away from work/school/college and from social activities, and therefore made considerably fewer contacts when they were ill than when they had recovered. Participants made approximately two-thirds fewer contacts when they were unwell.

There was an observed tendency for the more transient contacts (infrequent contacts and contacts not involving physical contact) to be more influenced by illness than stronger contacts (frequent contacts and physical contacts). This again is unsurprising, as stronger contacts are more likely to be made in the home.

The regression analysis made clear the important role played by the workplace (or school, or college) on social contacts – returning to work was, by some distance, the most significant predictor of increased numbers of contacts.

The seriousness of infection also appeared to play a role, again confirming our intuition; the greater the change in the number of symptoms reported, the greater the change in the number of contacts.

Differences between age groups emerged, with those in younger age groups tending to have a greater change in their contact patterns; this can be explained by the differences in social mixing patterns between schools and workplaces, with older individuals appearing to mingle in smaller groups than younger individuals.

The results of the study were highly statistically significant, and the changes in measured contact behaviour were large. However, the study suffered from a number of limitations.

There was an apparently extremely low response rate; almost 3800 questionnaires were distributed along with antiviral prescriptions, and only slightly over 300 returned. Although we have no way of verifying that survey forms given to a potential participant's 'flu friend' did in fact reach the potential participant, in the worst case this represents a response rate of only 8.4%. Furthermore, of the 308 follow-up surveys posted to participants who had completed the initial survey, only 179 were returned, of which 146 individuals reported that they were unwell when they completed the initial survey and had recovered by the time they completed the follow-up survey. Not only was this disappointing, but also it was some distance below the response rate obtained by a survey using very similar methodology: a two-part postal questionnaire survey (the EQ-5D study) carried out during the early stage of the 2009 swine flu pandemic received a response rate of 45%.[3] We postulate that, with hindsight, the low response rate was predictable; by the time the study was under way swine flu had been circulating in the UK for several months. After the initial media frenzy and the surge of attention that was generated by the launch of the NPFS, public interest had waned. By the time the sampling took place it was clear that the epidemic was in decline, and far fewer antiviral prescriptions were being distributed than at the epidemic's peak.[25] For example, according to the Health Protection Agency weekly national influenza reports,[26–31] there were an estimated 84,000 new cases in England in the peak week, the final week of October; by the middle of November, weekly incidence had fallen to 53,000 cases and to 22,000 by the end of November. Autumn weekly antiviral issues peaked in the penultimate week of October, had fallen by over 30% by the middle of November, and by over 40% by the end of November. With each passing week there were fewer cases, fewer potential participants, less media and public interest, and therefore a lower ability to sample and a lower likely response rate. Delays of a few weeks made a real difference. Had this study taken place earlier we believe that an improved response rate would have been achieved.

Unfortunately, the sluggish nature of the various stages of approval that the study was obliged to pass through meant that it was not possible to carry out the research in as timely a manner as had been anticipated. Because surveys were distributed at ADCs, some of which were NHS facilities, it was necessary to obtain local approval from each NHS trust within whose area questionnaires were distributed. Despite assurances that these local approvals would take 2–3 days, in practice, although some were indeed rapid, others took anything up to 2 months (and some never arrived). Clearly there is a need to reform the system of research governance to enable it to respond effectively to the urgent demands of real-time pandemic research if such research is to have a chance of success and of informing policy, as intended.

It is not clear whether or not there were non-response biases within our sample, although we would be surprised if there were not. When comparing individuals who returned both the initial and the follow-up survey with those who returned only the initial survey, we see that the latter group tends to be younger and to live in larger households. However, there was no significant difference between the groups in terms of either their reported severity of symptoms or their number of reported contacts when ill. Thus, though there are demographic differences, in key epidemiological and behavioural ways there is no significant difference between those who completed both surveys and those who completed only the initial survey. However, such comparisons tell us nothing about people who chose not to return the initial survey. What is almost certain is that the sample population was not a random sample of those who were infected with swine flu. Evidence collected from various sources and presented by the Health Protection Agency and other groups worldwide suggests that infection was concentrated in children.[25] Similarly, records collected by the NPFS show that antiviral distributions were also concentrated in younger age groups.[26–31] So, although our sample achieved a good coverage of age groups, it was not a random sample of the population of interest (i.e. those with swine flu).

At the time of the study, antiviral prescriptions were not issued to all individuals with swine flu, only to those who sought medication. Indeed, most participants received their diagnosis via a telephone line or a web page. Thus it may be that some, although reporting relevant symptoms, did not have swine flu. The participants probably ought, therefore, to be thought of as individuals with influenza-like illness rather than swine flu. It seems certain that those seeking antiviral medication were, in general, more ill than those who did not seek antiviral medication. Therefore, our sample is likely to be biased towards those with a more serious infection. This is supported by evidence from the EQ-5D study, carried out by the Health Protection Agency at the start of the pandemic and using similar methods to those used here, which aimed to recruit all cases of pandemic influenza; participants in the EQ-5D study reported an average health state (on a scale of 0–100) of 44 on their day of worst illness (AJ van Hoek, Health Protection Agency, 13 May 2010, personal communication), whereas participants in our study reported an average worst health state (on a scale of 0–10) of 1.98. More seriously ill people would be expected to be more likely to spend time away from their normal activities, and therefore to experience a greater change in their social contact behaviour than those with only mild infections. In this respect it is likely that our sample overestimates the extent of behavioural change. On the other hand, it might be that the principal difference between seriously ill individuals and those with less serious illness is the length of time taken away from work and other activities – the effect of taking time off may not depend on the seriousness of the infection, in which case our results may be more widely applicable.

However, it is not clear that our sample overestimates the behavioural change of those seeking antiviral medication. It might well be the case, for instance, that those who are most ill (and who therefore change their behaviour the most) would not feel in a fit state to fill in a survey. Furthermore, it is possible that those with the largest numbers of social contacts, when recovered, might decide that the contact diary would be too arduous to complete. These factors may lead to our data underestimating the effect of illness on social contact patterns.

Because the survey contains questions about participants' symptoms and the extent to which participants take time off work, it is hoped that we will be able to compare our data with other data sources, when they become available, to assess the extent of biases by level of illness or of work-related behavioural change, thus to allow some corrections of any observed biases to be attempted.

The study took place in England (the only part of the UK in which the NPFS was in operation), therefore it was not possible to assess whether there were different behavioural changes in response to infection in other parts of the UK.

As with any self-reported questionnaire, we cannot be certain that participants answered the questions in the way that was intended. There may have been deliberate misreporting of behaviour, or there may have been misunderstanding of the questions.

However, potential participants were provided with contact details (telephone number, e-mail address and postal address) for the research team and encouraged to make contact with any questions they had; only one query was received.

The brief school survey, although of limited size, gave the first survey-based quantitative measurements of the changes in contact patterns of school pupils occurring during school holiday periods. It is clear that school holidays have a large impact on social contacts, with children making about one-half of their number of term-time contacts during the holiday period. This observation helps explain the change in swine flu incidence that was seen during both the school summer holiday and, to a lesser extent, during the autumn half-term holiday.[25] Despite the low sample size, the measured behaviour change was highly significant. Although, as described, the study contained a range of biases and limitations, we are confident that the results obtained are a significant step forwards towards a more accurate understanding of the impact of illness on contact patterns. This understanding will facilitate more accurate mathematical modelling of epidemics, reduce the need for ad hoc approximations and aid future pandemic planning.

Chapter 5
Conclusions

The evidence from this study suggests that ill individuals make substantial changes to their social contact patterns. Participants in the study made approximately two-thirds fewer social contacts when they were ill compared with when they had recovered. The changes in contact patterns were strongly linked to absence from work and the severity of the reported illness, with age and household size also playing a role.

Epidemiological modellers should therefore be wary of using data about 'normal' contact patterns to parameterise mathematical models of disease spread, and should consider the implications of illness-related behavioural changes on model predictions. Of course, the changes measured here apply to symptomatic individuals, and care should be taken to use these data appropriately in cases when infected individuals may be asymptomatic or when infectiousness begins before symptom onset.

This study highlights areas for future research. Of particular value would be a more detailed study that aims to recruit a representative sample of cases; the study here, owing to its sampling methodology and the time constraints under which it took place, almost certainly ended up with a sample population that was experiencing relatively severe symptoms. Although such people are of interest, they may well display greater behavioural change than the average infected case. It would be of value, perhaps during forthcoming seasonal flu seasons, to carry out studies that measure the extent of behavioural change in a broader cross-section of infected cases.

The brief school study suggested that school children made approximately twice as many social contacts during school term as they do during the school holidays. As it was clear that children played a dominant role in the swine flu pandemic and might be expected to do so in future pandemics, and as it was apparent from the UK incidence data that normal patterns of school holidays had a significant impact on transmission, we advocate more detailed studies of the social contact patterns of school children, particularly focusing on differences between school terms and school holidays. Our experience, in this and other work (KTD Eames, unpublished), is that for school-based studies to be successful the research teams must be prepared to make a substantial investment of time and energy – such studies are therefore best conceived as long-term projects, achieving high levels of engagement with participating schools, rather than as rapid exercises. The presence of a pandemic cannot be taken as a guarantee of high participation.

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Contributions of authors

Dr Ken Eames (mathematical epidemiologist) conceived and designed the study, carried out the analysis, and wrote the report.

Natasha Tilston (mathematical epidemiologist) assisted with the study and carried out the analysis.

Dr Peter White (mathematical epidemiologist) conceived the study and assisted with the study design.

Dr Elisabeth Adams (mathematical epidemiologist) carried out recruitment for the study.

Professor John Edmunds (mathematical epidemiologist) conceived the study and assisted with the study design.

References

1. Anderson RM, May RM. *Infectious disease of humans*. Oxford: Oxford Science Publications; 1991.

2. Atchison C, Lopman B, Edmunds WJ. Modelling the seasonality of rotavirus disease and the impact of vaccination in England and Wales. *Vaccine* 2010;**28**:3118–26.

3. Baguelin M, Hoek AJV, Jit M, Flasche S, White PJ, Edmunds WJ. Vaccination against pandemic influenza A/H1N1v in England: a real-time economic evaluation. *Vaccine* 2010;**28**:2370–84.

4. Beutels P, Shkedy Z, Aerts M, Van Damme P. Social mixing patterns for transmission models of close contact infections: exploring self-evaluation and diary-based data collection through a web-based interface. *Epidemiol Infect* 2006;**134**:1158–66.

5. Cauchemez S, Valleron AJ, Boelle PY, Flahault A, Ferguson NM. Estimating the impact of school closure on influenza transmission from sentinel data. *Nature* 2008;**452**:750–4.

6. Conlan AJK, Rohani P, Lloyd AL, Keeling M, Grenfell BT. Resolving the impact of waiting time distributions on the persistence of measles. *J R Soc Interface* 2010;**7**:623–40.

7. Edmunds W, Kafatos G, Wallinga J, Mossong J. Mixing patterns and the spread of close-contact infectious diseases. *ETE* 2006;**3**:10.

8. Ford K, Sohn W, Lepkowski J. American adolescents: sexual mixing patterns, bridge partners, and concurrency. *Sex Transm Dis* 2002;**29**:13–19.

9. Glass RJ, Glass LM, Beyeler WE, Min HJ. Targeted social distancing design for pandemic influenza. *Emerg Infect Dis* 2006;**12**:1671–81.

10. Hens N, Ayele G, Goeyvaerts N, Aerts M, Mossong J, Edmunds J, *et al*. Estimating the impact of school closure on social mixing behaviour and the transmission of close contact infections in eight European countries. *BMC Infect Dis* 2009;**9**:187.

11. Heymann AD, Hoch I, Valinsky L, Kokia E, Steinberg DM. School closure may be effective in reducing transmission of respiratory viruses in the community. *Epidemiol Infect* 2009;**37**:1369–76.

12. Keeling MJ, Grenfell BT. Disease extinction and community size: modeling the persistence of measles. *Science* 1997;**275**:65–7.

13. Kretzschmar M, Mikolajczyk RT. Contact profiles in eight European countries and implications for modelling the spread of airborne infectious diseases. *PLoS ONE* 2009;**4**:e5931.

14. Mikolajczyk RT, Akmatov MK, Rastin S, Kretzschmar M. Social contacts of school children and the transmission of respiratory-spread pathogens. *Epidemiol Infect* 2007;**135**:1–10.

15. Mossong J, Hens N, Jit M, Beutels P, Auranen K, Mikolajczyk R, *et al*. Social contacts and mixing patterns relevant to the spread of infectious diseases. *PLoS Medicine* 2008;**5**:381–91.

16. Ferguson NM, Cummings DA, Fraser C, Cajka JC, Cooley PC, Burke DS. Strategies for mitigating an influenza pandemic. *Nature* 2006;**442**:448–52.

17. Germann TC, Kadau K, Longini IM, Macken CA. Mitigation strategies for pandemic influenza in the United States. *Proc Natl Acad Sci USA* 2006;**103**:5935–40.

18. Ghani AC, Baguelin M, Griffin J, Flasche S, Pebody R, van Hoek AJ, *et al*. The early transmission dynamics of H1N1pdm influenza in the United Kingdom. *PLoS Curr Influenza* 2009;16 November:RRN1130.

19. Fraser C, Donnelly CA, Cauchemez S, Hanage WP, Van Kerkhove MD, Hollingsworth TD, *et al*. Pandemic potential of a strain of influenza A (H1N1): early findings. *Science* 2009;**324**:1557–61.

20. Aral SO, Hughes JP, Stoner B, Whittington W, Handsfield HH, Anderson RM, *et al*. Sexual mixing patterns in the spread of gonococcal and chlamydial infections. *Am J Public Health* 1999;**89**:825–33.

21. Bearman Peter S, Moody J, Stovel K. Chains of affection: the structure of adolescent romantic and sexual networks. *Am J Sociol* 2004;**110**:44–91.

22. Read JM, Eames KT, Edmunds WJ. Dynamic social networks and the implications for the spread of infectious disease. *J R Soc Interface* 2008;**5**:1001–7.

23. Edmunds W, O'Callaghan C, Nokes D. Who mixes with whom? A method to determine the contact patterns of adults that may lead to the spread of airborne infections. *Proc R Soc Lond B Bio* 1997;**264**:949–57.

24. Mikolajczyk RT, Kretzschmar M. Collecting social contact data in the context of disease transmission: prospective and retrospective study designs. *Soc Networks* 2008;**30**:127–35.

25. Donaldson LJ, Rutter PD, Ellis BM, Greaves FEC, Mytton OT, Pebody RG, *et al.* Mortality from pandemic A/H1N1 2009 influenza in England: public health surveillance study. *BMJ* 2009;**339**:b5213.

26. Health Protection Agency. *Weekly national influenza report (week 49)*. London: HPA; 3 December 2009.

27. Health Protection Agency. *Weekly national influenza report (week 48)*. London: HPA; 26 November 2009.

28. Health Protection Agency. *Weekly national influenza report (week 47)*. London: HPA; 19 November 2009.

29. Health Protection Agency. *Weekly national influenza report (week 46)*. London: HPA; 12 November 2009.

30. Health Protection Agency. *Weekly national influenza report (week 45)*. London: HPA; 5 November 2009.

31. Health Protection Agency. *Weekly national influenza report (week 44)*. London: HPA; 29 October 2009.

Appendix 1

Survey forms

Initial survey

The first part of the survey asks for general (background) information. Note: each form was marked with a two-letter code denoting the ADC at which the survey was distributed – each ADC had its own two-letter code. Each returned form had a three-digit code appended to this ADC code, and the resulting compound code was written on the follow-up forms sent to that participant, allowing a participant's initial and follow-up data to be linked.

Contact diary

The same contact diary form was used for both the initial and the follow-up surveys.

Follow-up survey

The follow-up survey contained a shorter background questionnaire, and a second contact diary (identical to the first).

Background questionnaire

This questionnaire is for the person who has been given antiviral medication. If that person is a child then an adult can complete it on their behalf but should answer from the point-of-view of the child.

Today's date __________

Day of the week __________

About yourself (the person receiving antiviral medication)

(a) Age __________

(b) Gender __________

We would like to send you a follow-up questionnaire in about 2 weeks, so we can compare your social contact patterns while you are ill with your social contact patterns once you are feeling better. Your name and address will only be used to send the follow-up questionnaire. They will not be kept or passed on to anyone else.

Name (person to whom the follow-up questionnaire should be addressed):

____

Address __________________________

____

____

Postcode __________________

About your household

(c) How many people (other than you) live in your household? __________

(d) Please list their ages

____

(e) How many people in your household other than you **currently** have diagnosed swine flu? __________

- How many of them are taking Tamiflu (oseltamivir) or Relenza (zanamivir) antiviral treatment? __________

About your illness

(f) On what date did you first become unwell with swine flu? __________

(g) Are you still unwell today? YES NO (circle one)

- If NO, on what date did you recover? __________
- If YES, which symptoms do you have today (circle all that apply):

Fever	Chills	Nausea
Sore throat	Loss of appetite	Vomiting
Tiredness	Muscle pain	Diarrhoea
Headache	Joint pain	Red eyes
Cough	Blocked/runny nose	

(h) How do you feel today? (Mark a point on the line below)

worst imaginable health state 0---1---2---3---4---5---6---7---8---9---10 best imaginable health state

(i) Have you taken Tamiflu (oseltamivir) or Relenza (zanamivir) antiviral treatment?

YES NO (circle one)

- If YES, then...
  - On what date did you start taking the treatment? __________
  - Are you still taking the treatment? YES NO (circle one)

(j) On what date did you feel most ill with swine flu? ___________

(k) How did you feel on that day? (Mark a point on the line below)

worst imaginable health state	0---1---2---3---4---5---6---7---8---9---10	best imaginable health state

(l) Did you spend last night in hospital? YES NO (circle one)

Receiving care from others

(m) Has anyone taken time off work <u>to take care of you</u> whilst you have been ill with swine flu?

YES NO (circle one)

Using public transport

(n) Did you use public transport (bus/train/tram/underground) today?

YES NO (circle one)

(o) Would you normally use public transport (bus/train/tram/underground) today?

YES NO (circle one)

Your daily routine

(p) Do you normally attend work / school / college?

YES NO (circle one)

(q) Have you been to work / school/ /college today?

YES NO NOT APPLICABLE (circle one)

(r) Is your workplace / school / college currently closed due to swine flu?

YES NO NOT APPLICABLE (circle one)

(s) Have you taken time off work / school / college / playgroup / nursery / childcare group / social activities because of your illness?

YES NO NOT APPLICABLE (circle one)

- If YES, then are you off work / school / college / playgroup / nursery / childcare group / social activities **today** because of your illness?

  YES NO (circle one)

At the end of the day, once you have completed this background questionnaire and checked all the entries are correct, please return it and the completed contact diary to us using the pre-paid envelope provided.

Contact diary

Please cut off this column before returning the form.

This questionnaire is **for the person who has been given antiviral medication**. If that person is a child then an adult can complete it on their behalf but should respond from the point-of-view of the child.

Today's date ____________________ Day of the week____________________

Name (or description) of contact	Age (or age range)	Gender (Male or Female)	Was there skin to skin contact (Yes or No)?	How long? Over the day, for how long were you with this person (tick one)?					Where? Where did you meet this person (tick all that apply)?					How often? How often do you normally meet this person (tick one)?				
				Under 5 mins	5-10 mins	10mins-1 hour	1-4 hours	Over 4 hours	Home	Work/ School/ College	Travel	Leisure activity	Other	Daily or almost daily	Once or twice weekly	Once or twice monthly	Less than monthly	Never met before

Please turn over if you need more space

Name (or description) of contact	Age (or age range)	Gender (Male or Female)	Was there skin to skin contact (Yes or No)?	How long? Over the day, for how long were you with this person (tick one)?					Where? Where did you meet this person (tick all that apply)?					How often? How often do you normally meet this person (tick one)?				
				Under 5 mins	5-10 mins	10mins-1 hour	1-4 hours	Over 4 hours	Home	Work/ School/ College	Travel	Leisure activity	Other	Daily or almost daily	Once or twice weekly	Once or twice monthly	Less than monthly	Never met before

Did you include everyone you met today? __________

If not, how many other people did you meet today? __________

At the end of the day, once you have completed this contact diary and checked all the entries are correct, please return it and the completed background questionnaire to us using the pre-paid envelope provided.

Background questionnaire [follow-up]

This questionnaire is **for the person who completed the questionnaire that they received with their antiviral medication**; if that person is a child then an adult can complete the questionnaire on their behalf but should answer from the point-of-view of the child.

Today's date __________

Day of the week __________

About your household

(a) How many people in your household <u>other than you</u> **currently** have diagnosed swine flu? __________

- How many of them are taking Tamiflu (oseltamivir) or Relenza (zanamivir) antiviral treatment? __________

About your illness

(b) Are you still unwell with swine flu today? YES NO (circle one)

- If NO, what date did you recover? __________
- If YES, which symptoms do you have <u>today</u> (circle all that apply):

Fever	Chills	Nausea
Sore throat	Loss of appetite	Vomiting
Tiredness	Muscle pain	Diarrhoea
Headache	Joint pain	Red eyes
Cough	Blocked/runny nose	

(c) How do you feel today? (Mark a point on the line below)

worst imaginable health state 0---1---2---3---4---5---6---7---8---9---10 best imaginable health state

(d) Have you taken Tamiflu (oseltamivir) or Relenza (zanamivir) antiviral treatment?

YES NO (circle one)

- If YES, are you still taking the treatment?

  YES NO (circle one)

  - If NO, what date did you stop taking the treatment?

    ____

(e) What date did you feel most ill with swine flu? __________

(f) How did you feel on that day? (Mark a point on the line below)

worst imaginable health state 0---1---2---3---4---5---6---7---8---9---10 best imaginable health state

(g) Did you spend last night in hospital? YES NO (circle one)

Receiving care from others

(h) Did anyone take time off work <u>to take care of you</u> whilst you were ill with swine flu?

YES NO (circle one)

- If YES, then how many days have they taken off so far, including today (only counting days when they would have gone to work)?

  ____

Using public transport

(i) Did you use public transport (bus/train/tram/underground) today?

YES NO (circle one)

(j) Would you normally use public transport (bus/train/tram/underground) today?

YES NO (circle one)

Your daily routine

(k) Have you been to work / school / college today?

YES NO NOT APPLICABLE (circle one)

(l) Is your workplace / school / college currently closed due to swine flu?

YES NO NOT APPLICABLE (circle one)

(m) Did you take time off work / school / college / playgroup / nursery / childcare group / social activities because of your illness?

YES NO NOT APPLICABLE (circle one)

- If YES, then how many days did you take off? __________

At the end of the day, once you have completed this background questionnaire and checked all the entries are correct, please return it and the completed contact diary to us using the pre-paid envelope provided.

Appendix 2
School closure study

In summer 2009, in the early stages of the swine flu pandemic, several schools in the UK closed as a result of swine flu infections. It was expected that such closures would happen again in autumn 2009, either because of large numbers of cases in pupils or because of staff shortages owing to sickness. To help assess the impact of these closures on contact patterns, and therefore on transmission, it was planned to carry out a study similar to that described above, recruiting school children to complete a contact diary once when their school was closed as a result of swine flu and once when the school had reopened. Such a study would have helped us understand the impact of unplanned closures on children's mixing patterns and informed us about the use of school closure as a control policy.

However, the UK swine flu epidemic in autumn 2009 was milder than expected, and school closures did not occur. The planned study could not, therefore, take place. Instead, as the study materials had already been developed, we took the opportunity to carry out a half-term study – asking pupils to complete a contact diary once during their spring half-term holiday and once during term time. This adapted study clearly does not inform us about the effects of unplanned closures, but instead quantifies the impact of school holidays.

Eight schools in London and Sussex were recruited to take part, and approximately 1100 study packs were distributed. All questionnaire forms were contained in the study pack, so participants (or their parents/guardians) needed to keep hold of the follow-up survey forms until the appropriate date. The initial and follow-up surveys were clearly distinguished within the study pack, and clear instructions given to ensure that forms were completed on the correct days (all forms were dated by participants, and forms filled in incorrectly could be excluded from the analysis). This approach enabled us to avoid having to ask for anyone's name or address. In total, 134 forms were completed correctly (a response rate of approximately 12%) and, from these, a total of 119 paired contact diaries (response rate 10.9%) were obtained.

The results provided by those who participated are clear: during term time, participants reported an average of 18.51 contacts (95% confidence interval 17.03 to 20.00), whereas during the school holiday they reported an average of 9.24 contacts (95% confidence interval 8.15 to 10.32). There was a significant difference in the number of contacts reported in term time compared with during the half-term holiday (difference = 9.28; 95% confidence interval 7.77 to 10.79; $p < 0.0001$, Wilcoxon signed-rank test).

The sample is small and perhaps unrepresentative; however, within our sample children made approximately one-half of the number of social contacts during a day in the half-term holiday that they made during term time.

Appendix 3

Contact pattern changes – complete data set

In Chapter 3, *Figure 4* and *Table 3* show the changes in contacts recorded by participants who reported that they were unwell when they completed the initial survey but who reported that they had recovered by the time that they completed the follow-up survey. For completeness, *Figure 5* and *Table 5* show the equivalent data for all participants (i.e. including those who were still unwell when they completed the follow-up survey).

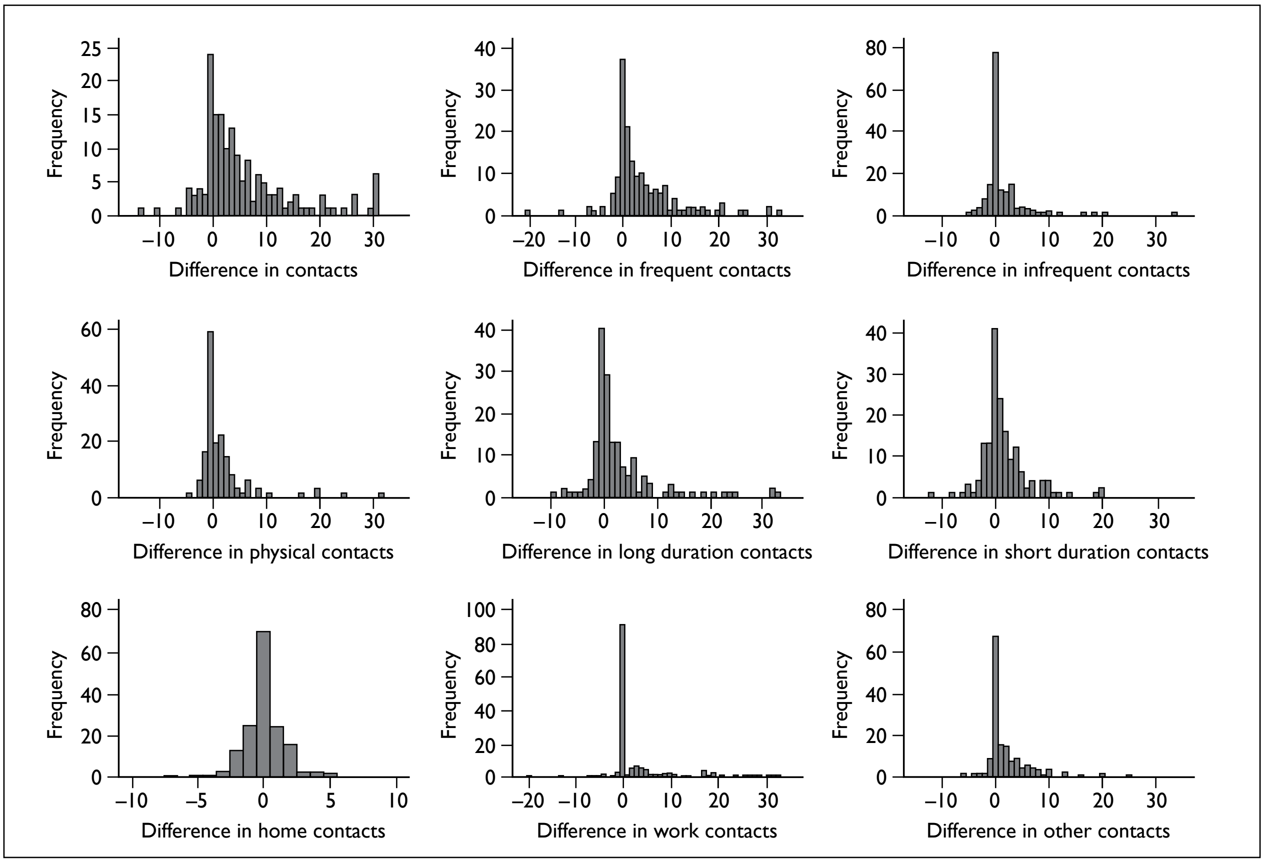

FIGURE 5 *Change in number of contacts reported in the initial and follow-up surveys; for each of the participants who completed a useable contact diary for both the initial and the follow-up survey (n = 165), the change in number of contacts is defined as the number recorded in the follow-up survey minus the number recorded in the initial survey.*

***TABLE 5** The number of contacts reported in the initial and follow-up surveys[a]*

Type of contact	Initial survey ($n = 172$), mean (SD)	Follow-up survey ($n = 168$), mean (SD)	Difference ($n = 165$)			
			Mean (SD)	Relative difference (percentage of follow-up mean)	Median (IQR)	p-value (median≠0)
All	3.74 (3.76)	9.76 (8.15)	6.08 (8.67)	62	4 (0 to 10)	<0.0001
All plus additional	4.12 (6.10)	12.10 (14.44)	8.06 (16.04)	67	4 (0 to 9)	<0.0001
Frequent	3.05 (3.48)	7.12 (6.90)	4.11 (7.31)	58	2 (0 to 7)	<0.0001
Infrequent	0.49 (1.07)	1.85 (4.06)	1.39 (4.34)	75	0 (0 to 2)	0.0001
Physical	1.72 (1.70)	3.76 (4.80)	2.06 (4.70)	55	1 (0 to 3)	<0.0001
Long duration	2.07 (2.25)	5.17 (6.38)	3.13 (6.58)	61	1 (0 to 4)	<0.0001
Short duration	1.06 (1.72)	2.71 (3.97)	1.68 (4.34)	62	1 (0 to 3)	<0.0001
Home	2.41 (1.61)	2.60 (2.09)	0.16 (1.75)	6	0 (–1 to 1)	0.3740
Work	0.78 (3.20)	4.36 (7.55)	3.64 (7.96)	83	0 (0 to 5)	<0.0001
Other	0.57 (1.32)	2.71 (4.25)	2.18 (4.41)	80	0 (0 to 3)	<0.0001

a The ‘difference’ figures refer to the difference in the number of contacts reported by those participants who returned a contact diary for both the initial and the follow-up survey ($n = 165$). Mean, SD, median and IQR of the difference are shown. The median difference is tested for significant difference from zero, and the p-value shown.