A new perspective from time use research on the effects of lockdown on COVID-19 behavioral infection risk

Short title: Changing behavioral risks of infection during lockdown; evidence from 2 waves of a time use survey

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Abstract:
We present findings from the first two waves of an innovative, population-representative, UK time-use diary survey conducted both pre- and mid-lockdown, using an online diary instrument that proved both reliable and quick-to-field. Combining diary information on activity, location, and co-presence to estimate infection risks associated with daily behavior, we show clear changes in such behavior related to infection risk between the pre and mid-lockdown periods: a substantial reduction of time spent in those behaviors with the highest levels of risk, accompanied by an equivalent increase in low-risk behavior. Because, in general, a populations' time use changes relatively slowly, the behavioral changes revealed may be interpreted directly as a consequence of the UK COVID-19 'lockdown' regulations. Subsequent waves will reveal the behavioral consequences of future changes in regulation.

One-sentence summary: Time-use diary research brings a new perspective on the effects of social distancing rules on behavioral risk: a UK example

A new perspective in understanding the effects of lockdown on COVID-19 behavioral infection risk

Governments around the world are urgently redesigning social distancing measures as they assess the trade-offs between economic and psychological distress and the need to avoid a resurgence in COVID-19. At a time when there is still limited capacity in respect both of immunization and track-trace technology, policy-makers must continue to rely on changes in people's daily behaviors to contain the virus. We present a tool enabling policy-makers to assess and quantify changes in the daily infection risk-related behaviors following social restrictions, and the impact they are having on overall risk levels. Using an innovative time-use diary survey conducted in real time during the period of peak lockdown, this paper provides a new view of the changing levels of behavioral risk pre- and during lockdown.

Many aspects of the COVID-19 pandemic are still poorly understood. But it is clear that the effective means of transmission of infection is *contact*: close interaction of an uninfected individual with an infected individual or location *(1)*. Demographic characteristics—age, sex, other social or environmental characteristics—are often used to model the heterogeneity of contact *(2,3,4)*. But these characteristics are less proximate to the routes of infection than are the daily patterns of behavior with which they are associated. Contact-based studies *(5,6)*, ask respondents who they met during specific periods (e.g. 'yesterday' or 'between these times'), or (for the GPS-driven BBC Pandemic Survey) while they were in a defined area over a 1-hour period *(7)*. While they record the physical proximity of contact (such as the speaking/touching distinction), contact-based surveys do not typically provide much information on the specific locations in which these contacts occurred, or on the likelihood that respondents were surrounded by people other than those they describe as 'contacts' (e.g. on a train, or in the cinema), or about activities/locations during which respondents did not report being in contact with specific others.

We bring to the study of the behavioral transmission of risk a new conceptual and methodological approach—from the perspective of time use research. The comprehensive 24-hour records of changing activities contained in 2 successive time-use diary surveys during the pre- and mid-lockdown periods reveal which behaviors (activities and locations and co-presences) were substituted under lockdown for pre-lockdown behavior (for example, lower-risk time at home substituting for higher-risk time at the workplace), enabling a picture of the changes in behavioral transmission risk associated with lockdown to be constructed.

Time-use diary data has been extensively deployed over many decades to understand trends in daily behavior *(8, 9,10)*. Time-use diary surveys provide nationally-representative samples of comprehensive, continuously-registered, records about the activities of daily life, including detail on their location and social context, through every 10 minutes of a 24 hour (or longer) period. Comparisons with objective activity measures (worn cameras, accelerometers) suggest that time-use diaries provide generally reliable and unbiased records of activity sequences and durations *(11)*. Deploying time-use diary evidence in this context has been done previously *(12,13,14)*, but not in respect of

combining multiple diary fields (activities, locations, co-presence and durations) to estimate risks, and not to report changing behavioral infection risks pre- and mid-lockdown.

Time-use diary surveys are generally accompanied by individual and household questionnaires, enabling detailed analysis by socio-economic and demographic characteristics to explore the distributional correlates and consequences of daily activity patterns. These questionnaires also provide information on aspects of time-use not covered by the diaries: for example monthly frequency of participation in various activities, permitting estimation of longer-term distributions of time across populations *(15)*; and questions on child-care arrangements, and on happiness, life satisfaction, health and wellbeing.

Materials and Methods

In 2016 the Centre for Time Use Research (together with the Dynata survey Agency and the Trajectory Partnership research Consultancy), developed a new online Click and Drag Diary Instrument (CaDDI), collecting population-representative (quota sample) from a market research panel across 9 developed countries including the UK and the USA *(16)*. We were able to field the same instrument with a similar UK sample, in May-June 2020 - at the peak period of lockdown, providing a real-time comparison with 2016 behavior. Diaries were collected on 2 or 3 days per respondent (including one weekday and one weekend day) per respondent, yielding approximately 1,000 diaries in each survey.

The quota samples were selected from a pre-existing panel to represent the UK population age >17, and reweighted to provide correct distributions of days-of-the-week and to correspond approximately to national population structures. Response days (2 or 3 per respondent; including one weekday and one weekend day) were randomly allocated to respondents. The two final samples included 1000 days in 2016, and 1005 in 2020. Response quality was comparable to other on-line diaries, with a mean of 17 distinct episodes recorded each day, and with unusually low levels of missing primary activity, location and co-presence data.

The CaDDI proved cheap to administer and relatively non-burdensome for respondents (with a mean 15-minute, median 12-minute, collection time). New waves of data collection using the same methodology are quick to commission (our May-June 2020 data collection took less than a fortnight from first consideration to enter the field).

The original instrument was also deployed (in 2016) in eight other developed countries (USA, France, Italy, Germany, Sweden, The Netherlands, Finland and Spain) with a total of 6000 individual respondents, most completing two diary days. The whole 2016 sample consists of 10,024 days collected between November 2015 and May 2016.

<u>Methods</u>

Taking cognisance of the epidemiological literature on contact risks, the estimates of risk levels we used were based on combinations of activity type, location and co-presence. We combined records of *activity* (36 categories), *co-presence* (7 categories, with up to four categories recorded simultaneously), *location* (3 categories), and duration, to estimate different levels of risk of infection for each 10-minute period through the day. The literature on transmission considers time at home alone or with members of the same household as lowest-risk, with the main focus for transmission of infection being contact with non-household members inside or outside the home. The virus is more likely to be transmitted indoors, in crowds, and through personal contact of over 15 minutes *(17,18)*. Our risk estimates located each activity/ location/ co-presence/duration combination in one of five risk-level categories ordered from low to high.

Our estimates of riskiness of location and co-presence status vary according to the activity—sometimes reflecting the nature of the activity itself (e.g. cinema implies the presence of other, non-household, individuals), and sometimes influenced by its characteristic location (e.g. indoors, enclosed, vs open-air). The multiple diary fields for each episode aid the risk-assignment process. For example, co-presence information may be supplemented from the activity fields, so "using public transport" can be taken to imply current or recent presence of other, non-household, individuals, while "childcare" implies presence of children. Registered activity may directly indicate risk: "jogging", for example, implying a low risk open-air location, "at the cinema", an enclosed space. The resulting estimates of risk accompanying the activity/co-presence/location combinations are shown in Table 1. Activities are shown grouped into categories that have similar patterns of risk attribution across the location and co-presence fields. The main two columns show 'in home' and 'away from home' location categories, each grouped into two co-presence categories: alone or with household members; with other, non-household members.

Table 1. Risk-level assignments, by activity, location and co-presence categories

	Assigned risk level			
	At home		Away from home	
	Alone/HH	Non-HH	Alone/HH	Non-HH
Activity number and description	(Column 0)	.(Column 1)	(Column 2)	(Column 3)
1 Sleeping	1	4	2	5
2 Resting	1	4	2	5
3 Washing, dressing	1	4	2	5
5 Preparing food, cooking, washing up	1	4	2	5
6 Cleaning tidying house	1	4	2	5
7 Clothes washing, mending, sewing	1	4	2	5
8 Maintenance of house, diy, gardening	1	4	2	5
21 Caring for own children	1	4	3	5
23 Help, caring for co-resident adults	1	4	3	5
27 Watching tv, video, dvd, radio, other music	1	4	3	5
28 Reading including e-books	1	4	3	5
29 Playing sports, exercise	1	4	3	5
32 Playing computer games	1	4	3	5
33 Spending time with friends, family	1	4	3	5
34 Telephone, text, email, networking, letters	1	4	3	5
36 Hobbies	1	4	3	5
11 Travelling: walking, jogging			2	3
12 Travelling: cycle			2	3
31 Walking, dog walking			2	3
13 Travelling: car			2	5
14 Travelling: bus, tram			5	5
15 Travelling: train, tube			5	5
16 Travelling: other			5	5
30 Going out to eat, drink eg pub, restaurant			5	5
35 Cinema, theatre, sports, cultural event			5	5
4 Eating, drinking, meal,at home	1	4	4	5
22 Caring for other children	3	4	3	5
24 Help,caring for noncoresid adults unpaid	3	4	3	5
9 Services: Doctor, dentist, hairdresser	3	4	3	5
26 Shopping, bank etc including internet	1	4	5	5
10 Church, temple, mosque, synagogue,prayer	1	4	5	5
17 Paid work including at home	1	4	5	5
18 Formal education	1	4	5	5
19 Recreational courses, study	1	4	5	5
20 Voluntary work for club, organisation	1	4	3	5
25 Work, study break	1	4	2	5

37 Other not listed (excluded)

We then, following the suggestion of de Cao et al. *(17)*, took account of the duration of events, assigning activities of only one 10-minute timeslot to the lowest risk level (level 1). This leads to only a small number of changes in our risk assignments.

Table A1 of the Appendix provides a look-up table for setting out the detailed composition of the nine activity/copresence/location categories shown in Figure 1, based on the activity number and column number information shown in Table 1.

Findings

Figure 1 presents change in behavior related to infection risk between the 2016 survey, and that conducted in May-June 2020. It shows historical change in both minutes per day, and daily participation rates, in the different combined activity/location/co-presence categories in the UK before and during the COVID-19 lockdown.

The pair of vertical colored stacked bars show the average minutes per day in nine groups of activity/location/co-presence combinations ordered, bottom to top, by risk level. The left-hand column refers to the 2016 pre-lockdown pattern, the right to late-May/early-June 2020. The horizontal bars on either side of the figure show the daily percentage of the sample engaging in each of the activity types at each time-point.

The changes following lockdown can be clearly seen. In particular, we observe the shift from more to less risky combinations of activity/location/co-presence categories during lockdown: the 71% of the day devoted to the least-risky category 1 activities in 2016 increases to 87% of the day in late May-early June 2020; and the 22% of the day spent in the most-risky (category 5) activities in 2016 decreases to 6%. At the bottom of both stacked columns the average daily time spent at home alone or with other household members doing self-care activities (including sleep, personal toilet, and meals), increases from 608 to 678 minutes, unpaid work tasks (cooking, cleaning, child-care, household maintenance), from 101 to 132 minutes, home leisure activities, and paid home working from 268 to 319 and 42 to 129 respectively. As we read up the column, risk category 2 includes activities such as leisure done away from home, but alone or with household members in open spaces (77 to 64 minutes), while risk category 3 includes activities such as leisure or caring done away from home in closed spaces, alone or with other household members (declining from 36 to 26 minutes). Risk category 4 comprises at home activities done with others not from the same household (23 to 8 minutes), and in the highest risk category, activities done away from home (such as leisure or care-giving) with others not from the same household, and paid work at the workplace, decline from 92 to 22 and 174 to 57 minutes respectively.
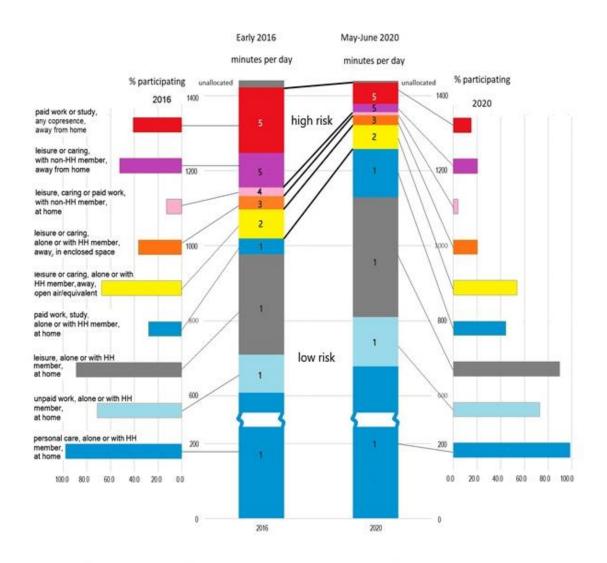
Figure 1: Time-at-risk and participation rates, grouped by risk level and activity/copresence/location combinations: UK pre- and mid-lockdown

Participation rates (horizontal bars) change similarly. The percentage engaging in the least risky (level 1) activities on any day increase between 2016 and May/June 2020, as do the sample members' rates of participation in them. As we move up the horizontal bars, the more-risky activities show continuously declining rates of participation. Away from home caring for non-household members declines from 53% to 20% on a random day, while paid work or study away from home declines from 41% to 15%.

Populations' time use patterns change, in normal times, only very slowly. So despite the 4-year distance from the earlier observation window, these unusually large historical changes in behavior may reasonably be interpreted as arising, mainly, from changes resulting from lockdown regulations in the UK.

Discussion

Recognizing that the risk of infection by COVID-19 is unlikely to disappear in the near future, it is likely that governments will need to continue to impose new restrictions on behavior (whether locally or nationally). In these circumstances it is imperative that policy-makers are provided with tools to be able to assess and quantify changes in the risk-related behaviors that follow these restrictions, and the impact they are having on risk levels. These survey waves provide an innovative view of behavioral changes in daily life as it relates to risk of infectious transmission. The continuous and comprehensive data provided by time-use diaries provides a more complete record of daily behavior, complementing contact-based instruments derived particularly from Polymod *(5,6)*. We will continue to record the changing pattern of daily behavior associated with new phases of the COVID-19 social regulation process (starting with a new tranche of data collection in late July 2020).

The CaDDI instrument, which is capable of rapid deployment for real-time measurement of behavioral change, opens up a further wide range of potential future applications:

- Beyond the measurement of the riskiness of behavior *on average*, the accompanying CaDDI questionnaire information allows analysis of *the distribution* of the behavioral risk of social distancing measures, enabling, for example, a cross-time assessment of distributional change by gender *(19,20)*, or by occupation.
- The CaDDI diary includes, in addition to the activity, co-presence and location diary fields deployed in this report, an additional field registering use of ICT devices, enabling investigation of how use of these technologies is changing among different groups of respondents over the course of social restrictions imposed in response to the pandemic.
- It also includes an instantaneous "how much did you enjoy the activity?" diary field, which can be used, in conjunction with the extensive questionnaire evidence about respondents' physical and mental health and wellbeing (available from the GHQ12 items of the accompanying questionnaire), to explore the subjective consequences of lockdown; for example, behavioral fatigue.

- The estimates of risk, particularly in relation to physical contact, can be validated and supplemented using empirical evidence from the CTUR's collection of nearly 200 days of combined diary, body-camera and accelerometer evidence *(21)*. This evidence, (with photographs at approximately 45 second intervals throughout the diary day) allows direct observation of the physical proximity of the diarists to others. In addition, occupation-specific risk to time at the workplace (based on the O*NET data adapted by the ONS to UKSOC), enables an extra layer of detail to be added to the existing risk classification *(22)*.
- The 2016 CaDDI survey provided similar information from 8 other countries (including the USA) opening the opportunity for low-cost cross-national pre- and post-COVID-19 research. There are also many larger-scale time use diary datasets, designed and collected by National Statistical Institutes, providing the potential for cross-national and historical comparisons, and for validation purposes (although their traditional large-scale survey design precludes deployment during pandemic conditions). The American Time Use Survey, and national surveys from the HETUS provide up-to-date (though longer to field) time-use datasets, as well as substantial legacy data for historical comparison. The Multinational Time Use Study archive includes harmonized versions of data from 25 (mostly developed) countries *(23)*.

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Appendix

Table A1. Lookup table for the nine aggregated activity/copresence/location categories shown in Figure 1

		risk levels	Including these cells in assignment table
1	Personal care, alone or with HH member, at home	1	1.0 2.0 3.0 4.0
2	Unpaid work, alone or with HH member, at home	1	5.0 6.0 7.0 8.0 21.0 23.0
3	Leisure, alone or with HH member, at home	1	27.0 28.0 29.0 32.0 33.0 34.0 36.0
4	Paid work, study, prayer, alone/HH member, at home	1	26.0 10.0 17.0 18.0 19.0 20.0 25.0
5	Leisure or caring, alone or with HH member, away, open air/equivalent	2	1.2 2.2 3.2 5.2 6.2 7.2 8.2 11.2 12.2 31.2 13.2 25.3
6	Leisure/caring, alone/with HH member, away, enclosed space	3	21.2 23.2 27.2 28.2 29.2 32.2 33.2 34.2 36.2 4.2 22.2 24.2 9.0 9.2 20.2 11.3 12.3 31.3
7	Leisure/caring or paid work, with non-HH member, at home	4	1.1 2.1 3.1 4.1 5.1 6.1 7.1 8.1 9.1 21.1 23.1 27.1 28.1 29.1 32.1 33.1 34.1 36.1 26.1 10.1 17.1 18.1 19.1 20.1 25.1 22.1 24.1
8	Leisure/caring, with non-HH member, away from home	5	1.3 2.3 3.3 5.3 6.3 7.3 8.3 21.3 23.3 27.3 28.3 29.3 32.3 33.3 30.3 35.3 34.3 36.3 14.3 15.3 30.3 35.3 34.3 36.3 14.3 15.3 16.3 30.3 35.3 4.3 22.3 24.3 9.3 26.3 10.3 19.3 20.3
9	Paid work or study, any copresence, away from home	5	17.3 18.3 19.3 20.3 25.3 14.3 15.3

Notes: Table A2 provides a lookup table setting out the detailed composition of the nine activity/copresence/location categories of Figure 1, based on the activity number and column number information shown in Table A1. For example Category 1, low risk activities in the "Personal care, alone or with HH member, at home" activity group is comprised of four cell references (activity number + column number): 1.0 (for activity 1; time spent asleep, and column 0; at home, alone or with other household members); plus cell reference 2.0 (resting time, again at home, alone or with other household members) plus cell 3.0…. and so on.