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Enhancing social surveys through the postal collection of shed milk teeth: an example of a large-scale cost-effective collection on a longitudinal study

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Social scientists and health researchers often need valid and reliable health measures from survey respondents to address key research questions, whether on environmental risks, weight and nutrition, physical activity or risky health behaviours, such as smoking. There are long-standing debates on the validity of self-reported measures of health status and health behaviours in representative sample surveys. Such problems are particularly acute when the health status or behaviour occurred in the past and depends on retrospective recall. Increasingly social surveys are collecting direct biomarkers to provide more precise information on health status and behaviours. While much of this biomarker collection requires clinic visits or in-home nurse visits, some biomarkers are amenable to less costly and intrusive collection. Shed milk teeth are a good example of a stable biomarker that can provide extensive information on early (including in utero) child environmental and family contexts that may shed valuable light on childhood and adult health and social outcomes. Shed milk teeth are also potentially cheap (and non-intrusive) to collect as well as to store. In this paper we report on the collection of shed milk teeth in a nationally representative sample in the UK using postal methods. We conclude that for surveys involving children, particularly interview-led surveys, incorporating the postal collection of shed milk teeth could prove a cost-effective enhancement, providing valuable environmental, nutritional and health information.

Keywords: milk teeth, biomarkers, biosocial survey, postal data collection, nonresponse

My mouth is full of decayed teeth and my soul of decayed ambitions.

James Joyce

The most obvious sign of undernourishment is the badness of everybody's teeth. Indeed you see very few people with natural teeth at all . . . even the children's teeth have a frail bluish appearance . . .

George Orwell, The Road to Wigan Pier

1 Introduction

The direct collection of biomarkers and environmental health measures in multi-purpose, as well as health, surveys is increasingly used to supplement and enhance the information collected from respondents on their health status, health behaviours and environment. Such biomarkers have an important role to play in social science and epidemiological research in understanding disease pathways, the early antecedents of later health conditions, the social patterning of health outcomes and health behaviours, and the particular contours and correlates of key current concerns such as childhood and adult obesity. They also shed light on the links between particular health behaviours and outcomes and other domains of life such as risk-taking, cognitive development, and social relationships. The introduction of such biomarkers in multi-purpose social surveys – the development of the 'bio-social survey' – has opened up a range of new possibilities for research (Weinstein, Vaupel, & Wachter, 2007). It has allowed an enrichment of social survey research as well as making such surveys of considerable interest to health researchers typically accustomed to smaller scale specialist surveys with fewer social scientific measures, opening up new possibilities for effective interdisciplinary research.

Self-reported measures of health status and health behaviours are known to have issues of social desirability (Tipping et al., 2010) and unreliability (Bound, 1991) and are particularly problematic if asking about retrospective experiences or practices. Hence, despite arguments in their favour (Benitez-Silva, Buchinsky, Chan, Cheidvasser, & Rust, 2004), objective measures are often preferred to provide consistency of measurement across different social

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groups or to validate self-reports (Vartiainen, Seppälä, & Puska, 2002). Moreover objective measures provide information that may be hard or even impossible to collect through self-report, such as (retrospective) environmental exposures or nutritional status of mothers in pregnancy. Despite developments in surveying children even at young ages (Borgers, de Leeuw, & Hox, 2000), self-report may also be less appropriate for young children. At the same time, having good measures of childhood nutritional status or health care access is of critical interest in understanding the long-term consequences of childhood health on adult outcomes. While subjective and self-report measures of health and health status are important in ascertaining how individuals locate themselves in terms of health status and behaviour, increasingly survey self-reported measures are regarded as being complementary to objective measures rather than as substitutes for them (Sirven & Debrand, 2012), increasing the urgency of collecting robust biomeasures from national representative populations.

The collection of biomeasures is, however, typically costly and can also be burdensome for respondents. There have been a number of developments to increase the ease of collection and reduce both cost and respondent burden, for example by interviewer collection of dried blood spots in place of clinic attendance, or nurse visit whole blood collection (McFall, Conolly, & Burton, 2014; Williams & McDade, 2009). But collection still often requires substantial resource, which may be hard to achieve for large, nationally representative population samples within funding constraints. Burden may be more easily managed where the population is already somewhat 'compliant' as in a longitudinal sample, and may be further eased by increasing the respondent's own management or control over the collection. Postal methods, for example, can both reduce costs and enable the respondent to engage with the data collection process more proactively and with greater privacy. On the other hand, postal methods tend to increase nonresponse, even in engaged populations (Coleman et al., 2011; Elliott, Johnson, & Shepherd, 2008; Fuller, Power, Shepherd, & Strachan, 2006). While nonresponse does not necessarily result in a biased sample of respondents (Roberts, Vandenplas, & Stähli, 2014), it increases the likelihood that the sample will be skewed, often along predictable lines of education, family stability and salience of the collection in terms of own health status. Indeed, the feedback on the health measures that respondents receive may be a major incentive in promoting their participation.

In light of these interests in developing social surveys as biosocial surveys to enhance their scientific value, alongside concerns with cost and respondent burden, the collection of exfoliated milk (deciduous) teeth, while still relatively rare in social surveys can offer exciting potential returns for studies containing children. This is particularly the case for longitudinal or child cohort studies, where those children will be followed up subsequently. Shed milk teeth are, moreover, relatively cheap and non-burdensome to collect: they have already been shed, they do not require particular conditions of delivery or storage, and they can easily be supplied by the respondent (or their parents) without interviewer / nurse guidance or intervention. They thus provide a cost-effect option, and one that is unlikely to negatively impact response to the survey in other domains. On the other hand teeth are not shed at predictable times, creating challenges for effective collection and reminder strategies, which may negatively impact on response. Dependence on postal methods may therefore lead to relatively low levels of return.

In this paper we report on the postal collection of shed milk teeth in a child cohort study. The primary aim of the collection described was to estimate lead exposure, and to compare with geographical measures of environmental lead. But the resource was of a sufficient scale and was collected with the intention that it could provide a research resource for other analyses. Overall, the project succeeded in collecting 4,168 teeth from 2,997 families across the UK at the modest cost of around £10 per tooth, and using just one round of reminders to participants. The response rate was, however, only 21 per cent; and, as with biomarker collection more generally, showed some skew towards more affluent, educated, and advantaged families. Nevertheless, there was sufficient spread both across different types of geographical area and social characteristics to enable the effective investigation of associations between social background and the health and nutrition information contained within teeth, as well as for sub-group analysis. We conclude that the postal collection of teeth represents a promising development for the expansion of social surveys at relatively low cost. We also consider that further steps could still be taken to improve the level of collection and enhance response rates.

In the next section we outline the potential research agendas that could benefit from the analysis of exfoliated milk teeth. We then consider developments in biosocial survey data collection and in postal collection in particular. This situates the postal collection of milk teeth as a biological enhancement to a social survey. We describe the approach to collection from participants in the UK Millennium Cohort Survey, before discussing response, and the extent to which that was patterned across key sociodemographic factors. We highlight the extent to which viable samples were provided across key domains of interest, before concluding and providing suggestions for further development of deciduous teeth collection within longitudinal social surveys with children.

2 Background

2.1 The scientific value of teeth

Exfoliated milk teeth offer a rich source of scientific analysis in a number of domains. They can provide invaluable information about exposure to environmental pollutants (C. Brown et al., 2004), in particular toxic metals (Adams, Romdalvik, Ramanujam, & Legator, 2007), both in utero as well as in early childhood. Lead exposure has received the most attention (Gulson & Wilson, 1994; Shepherd et al., 2012, e. g.), but milk teeth can also be revealing about exposure to mercury (Adams et al., 2007) and cerium (C. Brown et al., 2004), and their potential links to subsequent health and behavioural conditions. The long-term effects of such exposure are not fully determined in all cases, though there is now a substantial body of evidence on the detrimental impacts of lead (Chandramouli, Steer, Ellis, & Emond, 2009). The build-up of radioactive strontium-90 in shed milk teeth investigated in the St Louis baby tooth study (Rosenthal, Gilster, & Bird, 1963), as a result of increased environmental exposure to nuclear testing, was also associated with higher vulnerability to certain cancers (Mangano & Sherman, 2011). Teeth are also informative about maternal nutritional status and may provide insight into early life nutritional stress (Beaumont, Montgomery, Buckberry, & Jay, 2015); while patterns of barium in dentine can shed light on exclusive breast-feeding and weaning patterns (Austin et al., 2013).

Shed milk teeth are of course also informative about levels of caries (tooth decay) among young children. As the Orwell quotation from the opening of this paper indicates, tooth decay is closely linked to nutrition to dietary practices; and teeth are informative more generally about nutrition (Alvarez, Eguren, Caceda, & Navia, 1990). The National Health and Nutrition Examination Survey (NHANES) in the US has been monitoring the oral health of children over an extended period and has identified caries rates of 42 per cent in children aged 2-11 with untreated rates of 23 per cent (See http://www.nidcr.nih.gov). Rates of treated and untreated caries showed variation by sex, race and ethnicity, and income level. The direct measurement of caries, both treated and untreated provides information both on nutritional quality – which is notoriously hard to measure in general surveys, and also on access to treatment.

Techniques for the analysis of teeth have also revealed the potential of inductively coupled plasma-mass spectrometry (ICP-MS) for isolating the timing of particular exposures (Shepherd et al., 2012; Webb et al., 2005). Mass spectrometry is an intensive, and has been an expensive, procedure and sample sizes for analysis of teeth are typically small: existing studies of teeth typically use only between 15 and 25 teeth, allowing for an extensive range of research projects to draw on the same resource if it comprises a substantial number of teeth.

Combining the collection of deciduous teeth with the background, contextual and socioeconomic, educational, behavioural and cognitive measures of a social survey therefore potentially provides a rich resource, linking child environmental and nutritional exposures to family and social context and to later adult outcomes. It also provides the opportunity for understanding geographical, socio-economic variations in exposure to different poisonous metals, and the consequences for cognition and development.

2.2 Transforming social surveys into biosocial surveys

While specialist, cross-sectional health surveys have collected biomeasures for a substantial period (e. g. the Health Survey for England) and some cohort studies started life as medical health related studies (e. g. the UK National Survey of Health and Development, begun in 1946), there has been increasing attention to enhancing primarily social surveys through the collection of biomeasures. This has now become a particular interest for many longitudinal surveys, since they offer particularly rich ground for biomarker collection. They often represent a relatively engaged sample who are more likely to comply with requests for biomarkers; prior information on the sample may allow the targeting of particular subpopulations or inform the presentation of information on the biomarkers; and sample members' details are kept updated and they are regularly followed-up, which may facilitate a wider range of possible applications, and timing of applications, such as advance notice followed by interviewer placement or interviewer collection at the point of the survey.

Most importantly, respondents in longitudinal studies are tracked over time so the short- and long-term implications of health status and health behaviours can be investigated, reaping the full rewards of the collection of measures. While a number of longitudinal studies have combined biomedical and social data collection from the outset, such as the Health and Retirement Survey, or the English Longitudinal Study of Ageing (ELSA), longstanding and more recent longitudinal 'social' surveys are increasingly becoming 'biosocial' through the addition of biological data collection (Buck & McFall, 2012; Schonlau et al., 2010, see e. g.). Longitudinal studies with child samples or child cohort studies offer the potential to collect childhood biomeasures and track their influence in later life outcomes (Li, Hardy, Kuh, & Power, 2015, e. g.), as well as charting protective factors.

With the distinction, then, blurring between medical cohorts, typically premised on clinic based data collection, and social (longitudinal) studies, with data collection typically carried out in the home, a range of ways of collecting valuable biological data are being explored and implemented. Thus, we have seen collection of direct measures of cortisol (Fuller et al., 2006), blood (McFall, Booker, Burton, & Connolly, 2012), saliva (Calderwood, Rose, Ring, & McArdle, 2014), spirometry (Clennell, Kuh, Guralnik, Patel, & Mishra, 2008, e. g.), physical activity through accelerometers (Rich et al., 2013), grip strength (Dodds et al., 2014, e. g.), as well as measures of cognitive facility (M. Brown & Dodgeon, 2010, e. g.) in a range of longitudinal surveys (see also the discussion in Calderwood et al., 2014).

Biomarkers are, however, typically both costly to collect – and store – and relatively burdensome or intrusive for respondents. Thus, while the data obtained may be more reliable than that from respondent report, they may be off-putting for respondents and are therefore likely to invite response from those most engaged with the study or those perceiving a potential benefit from feedback about the particular health measure being carried out. This is one reason why they have been found to be particularly successful in studies of older adults. Typically, responses to biomarker collection are skewed in terms of age, social class and education (McFall et al., 2012). The degree of bias relative to research questions of interest makes this more or less of a problem for subsequent analysis.

For these reasons, there have been a range of initiatives to explore ways of collecting data that are cheaper, more inclusive and more under the respondent's control than the clinic based approaches previously used in a number of health surveys and extensively exploited by, for example, the Avon Longitudinal Study of Parents and Children (ALSPAC). We have thus seen in-home nurse visits used in *Understanding Society* (McFall et al., 2012) and ELSA, following a model already used in a number of cross-sectional health surveys, such as the Health Survey for England. However, such in-home visits are still costly and risk drop-out between the initial interviewer visit and the follow-up nurse visit. Greater coverage and lower cost can potentially be achieved by exploiting interviewer collection at the point of survey. Jaszczak, Lundeen, and Smith (2009) demonstrated the potential for in-home interviewer collection of high quality biomeasures including blood spots, saliva, blood pressure and vaginal swabs in a large scale study (Williams and McDade, 2009; see also McDade, Williams, and Snodgrass, 2007). Following such examples, UK longitudinal studies have piloted blood spot and saliva collection by specially trained interviewers (Calderwood et al., 2014; McFall et al., 2014), and have collected oral fluid from children as young as three years old with parents administering the swabs under interviewer guidance (Bartington, Peckham, Brown, Joshi, & Dezateux, 2009). The US Fragile Families study, meanwhile, used interviewers to collect saliva samples from both parents and children during in-home visits (see http://www.fragilefamilies.princeton.edu/).

2.3 Postal collection of biomeasures

Postal measures bring further reductions in costs and increase flexibility and respondent control, while interviewer placement may still aid response. Salivary cortisol and saliva suitable for DNA extraction were collected from the National Child Development Study through interviewer/nurse placement and respondent return (Elliott et al., 2008; Fuller et al., 2006). Interviewers for the Millennium Cohort Study briefed parents and children in families participating in the age 7 survey about an accelerometry study, and consenting families were subsequently sent an accelerometer and instructions for wear and subsequent postal return (Rich et al., 2013). The Wisconsin Longitudinal Study, by contrast, depended entirely on respondent administration for saliva samples (Herd, Carr, & Roan, 2014). These postal returns have demonstrated a relatively high degree of success with response rates in some cases of up to 70 per cent, though somewhat lower in the case of the accelerometers (47%). Postal methods may be especially suitable where collection is aided by enhanced privacy, such as with saliva collection, involving spitting (Croes & Oliver, 2007). However, when Coleman et al. (2011) explored the viability of obtaining rectal swabs by mail following a phone interview, response was somewhat lower (25%) than when the interviewer waited for the swab following a face-to-face interview (34%).

Since postal collection depends on the respondent for the implementation of the collection and hence there is more limited opportunity to implement quality control procedures, postal methods are more likely to provide good data where the biosample to be collected is robust and unlikely to decay (such as with deciduous teeth) and where the process is relatively straightforward. As noted, postal methods are particular suitable when collection is extended, as with cortisol or physical activity measurement – or where it is unpredictable. However, as with postal questionnaires, postal collection of biological samples faces the risk of higher rates of nonresponse. Nonresponse in itself may not be an issue if it does not lead to biased estimates, or invalidate attempts to investigate relevant associations. Response rates are not themselves indicators of bias or its absence (Groves, 2006; Roberts et al., 2014) and longitudinal studies can offer particular advantages in providing a rich set of covariates against which to estimate – and potentially adjust for – bias. Moreover, assessing population prevalence is not generally the aim of studies of teeth, which have tended to focus on particular towns or specific study areas. Analysis of teeth is typically based on very small numbers (15-25), from which associations are estimated. Hence, large-scale collection has the potential to provide samples that can be closely matched to relevant family conditions and behaviours of interest to the research question at hand. Nevertheless, obtaining sufficient samples and coverage of relevant characteristics or environmental contexts to undertake meaningful analysis could still be impacted by very low response rates.

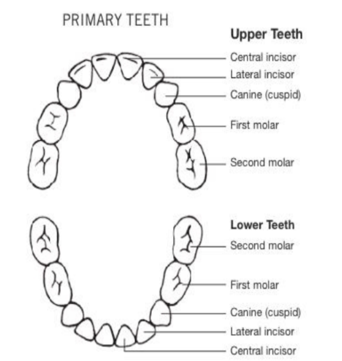
In view, then, of potential concerns with minimising both financial cost and respondent burden while obtaining good quality samples in biomarker collection, the postal collection of shed milk teeth in longitudinal social surveys involving children offers the potential for substantial scientific returns without the levels of intrusion (the teeth are already shed) or respondent burden that often are associated with biomarker collection. They are also stable and therefore do not involve extensive costs for either collection or storage. Shed milk tooth collection therefore offers a promising route to transform a social survey into a biosocial survey at little cost and, for longitudinal surveys, with little risk of increasing attrition. We go on to provide an example of such a collection and the extent to which it delivered on this promise.

3 Collecting shed milk teeth from participants in the Millennium Cohort Study

The *Every tooth tells a story* project was carried out as a collaboration between the Centre for Longitudinal Studies (CLS) and researchers from UCL's Institute of Child Health, and was funded by the Health Protection Agency at a cost of under £50,000[1]. The aim of the project was, in the first instance, to provide an assessment of children's environmental lead exposure as reflected in the build-up in their teeth. Tooth enamel can reveal pre- as well as post-natal exposure to lead (Shepherd et al., 2012), and, unlike blood, can capture accumulated exposure (Rabinowitz, Leviton, & Bellinger, 1993). Lead exposure has been associated with a range of adverse developmental outcomes among children, both educational and behavioural (Chandramouli et al., 2009); and there is now a consensus that there is no safe level of blood lead among children (M. Brown & Margolis, 2012). Despite reductions in environmental lead exposure, indicative results from blood lead levels in ALSPAC have suggested that severe lead levels may remain an issue for a small proportion of children (Chandramouli et al., 2009). However ALSPAC only covers one geographical area, and there are in the UK no nationally representative studies of either blood or tooth lead levels.

Although the lead research was the primary motivation for the tooth collection, and was the basis on which it was funded by the Health Promotion Agency (HPA), the collection of teeth in the MCS was also intended from the outset to provide a wider resource to enable investigation of other questions as they arose.

The design of the collection was intended to capitalise on the longitudinal sample of the Millennium Cohort Study (MCS), to align with questionnaire data collection and to draw on contact procedures already in place. The Millennium Cohort Study (MCS) is a UK-wide prospective study of the social, economic and health-related circumstances of around 19,000 children born in Great Britain and Northern Ireland at the turn of the new century. First surveyed at nine months, the families have subsequently been followed up at ages 3, 5, 7, 11 and most recently 14. For further details of the sample design see (Plewis, 2007).



Type of tooth	N	%
Upper teeth		
Central incisor	775	18.6
Lateral incisor	487	11.7
Canine	117	2.8
First molar	116	2.8
Second molar	12	0.3
Lower teeth		
Central incisor	529	12.7
Lateral incisor	521	12.5
Canine	217	5.2
First molar	103	2.5
Second molar	12	0.3
Don't know	803	19.3
Unknown	476	11.4
Total	***4,168***	***100%***

Figure 1. Type and number of teeth received

Economy in administration was facilitated by piggy-backing the initial mailing and the invitation to participate with the standard pre-notification for the Age 7 Survey. Families were mailed an invitation to take part in the tooth project with the pre-notification mailing sent out to cohort members and their families in early 2008. If they agreed, they were asked to post one or more of their child's shed teeth back[2]. The initial mailing included an information sheet giving details about the study, a reply paid envelope, a small, lead-free plastic bag labelled with their child's unique MCS bar code for the teeth to be placed in and a tooth chart for the parent to mark, if known, which tooth or teeth were being sent (see Figure 1).

Returned teeth were logged using the bar code label onto a database and then stored in separate lead-free plastic bags at room temperature in a locked cabinet. Personnel who logged and stored the teeth did not know the identity or name of any child who had returned a tooth.

A reminder letter with the same contents was sent in 2010 to prompt the return of existing teeth and of those that had been shed somewhat later than the initial mailing. This resulted in a number of further teeth being returned, and the latest tooth was sent in 2011. Relative to postal implementation used for collection of biosamples on other surveys the reminder strategy was non-intensive (compare, for example, Rich et al., 2013). This was partly due to the fact that there was no specific time at which collection was expected to have occurred; and partly due to the limited resources available to

[1]The total award was £41,500 in 2008 prices. Of this, costs for the administration of the postal survey and production of the related materials were around £24,000; and the remainder related to costs of receipt and logging of the returned teeth. A small additional sum (of around £4,000) allowed the reminder mailing to be carried out.

[2]Return of a tooth was taken as implicit consent and the approach was approved by the East London and the City Research Ethics Committee in January 2007

Table 1
Number of teeth returned per child, children participating in "every tooth tells a story" study

No. of teeth returned	N (children)	%
1	2266	74.8
2	544	17.9
3	135	4.5
4	50	1.6
5+	36	1.2
Total	3031	100

support the study. Nevertheless, the single reminder mailing did increase the overall number of teeth returned, resulting in a final cost of a little over £10 for each tooth returned.

Feedback on the outcome of the postal collection was provided only after the final teeth were received. This feedback was included in a regular feedback mailing in 2013 to the children of the MCS and their parents, a mailing which was linked to the Age 11 survey that had taken place in 2012. The feedback leaflet recounted the numbers who had responded and their distribution. Some individual family responses suggested that parents would like to have had more information about the lead levels in their areas or the extent to which they were at risk. Moreover, feedback on the project – and ideally early results – prior to the end of collection might, arguably, have increased response, by making the collection more salient to respondents.

3.1 Response

The issued sample for MCS4 and *Every tooth tells a story* comprised 17,029 families. Of these, 13,857 (81.4%) families and 14,043 children participated in the age seven face-to-face survey; and 2,997 (17.6%) families took part in *Every tooth tells a story*. While the vast majority of those who sent a tooth also participated in the Age 7 survey, the invitation to participate in *Every tooth tells a story* study was initiated prior to the main MCS4 data collection and thus 64 (2.1%) of the 2,997 families contributed a tooth without then taking part in the main Age 7 survey.

An individual tooth bag was returned for 3,070 cohort members, of which 39 bags had no teeth in them, or the tooth had been lost in transit. For the 3,031 children returning a valid tooth, 2,967 (97.9%) were singletons, 52 were twins and 12 were triplets. A single tooth was sent in for 2,266 (74.8%) children and multiple teeth for 765 (25.2%) children from 758 families. In total, 4,168 teeth were returned. This makes it the largest study of milk teeth to have been carried out in the UK. While two teeth are available for 544 children, a maximum ten teeth were returned for two children. Table 1 describes the varying number of teeth returned per child.

Families were asked to send in their child's front teeth (upper or lower incisor). Figure 1, showing the chart that families were sent to help them identify which tooth they were sending, also lists the number of each type of tooth received, as labelled by the parent, including the "don't knows" and unknown (where nothing was marked on the sheet). The large numbers of "don't knows" and unknowns indicates one of the potential hazards of postal collection in terms of data quality, in that there is likely to be much lower compliance with such labelling and provision of additional information without additional prompts or follow- up. Nevertheless, over 2,300 teeth (55%) were recorded as the target incisors. The overall numbers of both teeth and participating families was thus high and larger than any previous study.

3.2 Coverage

Coverage of teeth collection was of particular interest in relation to two aspects of the survey. Given the primary aim of the study was to collect teeth for the analysis of lead and comparison with environmental lead levels, a first key concern was the extent to which there was geographical coverage over different sorts of area, and in particular areas with different levels of environmental lead. While there was some variation in response across regions, teeth were returned from all regions of the UK (Figure 2). For the families who sent in at least one of their child's teeth, it was possible to link in a measure of the lead concentration in the soil based upon the post-code of their address at the Age 7 survey. This lead measure was provided by the Small Area Health Statistics Unit (SAHSU), MRC Centre for Environment and Health, Imperial College London. The lead estimates in soil (mg/kg) were derived from a continuous lead map, created as part of the Environmental Health Atlas, currently developed by SAHSU[3]

A measure of the lead concentration in the soil based linked to their postcode was available for 90 per cent of the families who returned a tooth (n=2,642). Lack of data was almost exclusively associated with the 278 families living in Northern Ireland, where this information was not available. The lead concentration levels for families returning at least one of their child's teeth ranged from 19.76 mg/kg to 53.00 mg/kg. The average was 43.03 mg/kg with a standard deviation of 5.02. This compares with typical (median) concentration of lead levels in soil in England and Wales, according to the Environment Agency in 2011 of 40 mg/kg (See http://cdn.environmentagency.gov.uk/geho0411btqt-e-e.pdf).

For the purposes of investigating the distribution of the tooth sample across different environmental conditions, ar-

[3]For further details see Table 2 on www.sahsu.org/content/sahsu-databases. The map was based on sampling data from the Centre for Ecology and Hydrology as part of the 2000 Countryside Survey: http://www.countrysidesurvey.org.uk/about/project-history/countryside-survey-2000

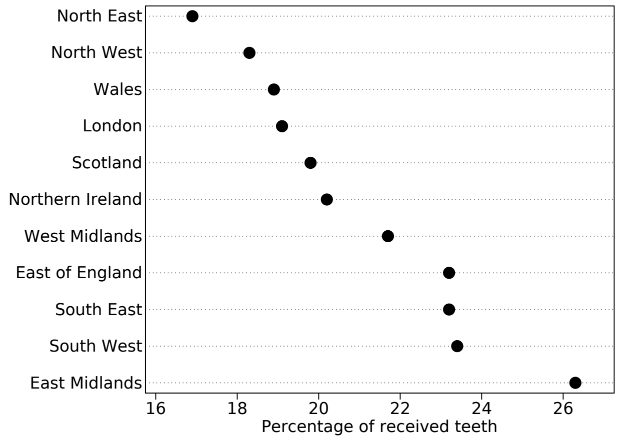


Figure 2. Percent of MCS4 families returning a tooth by geographic location

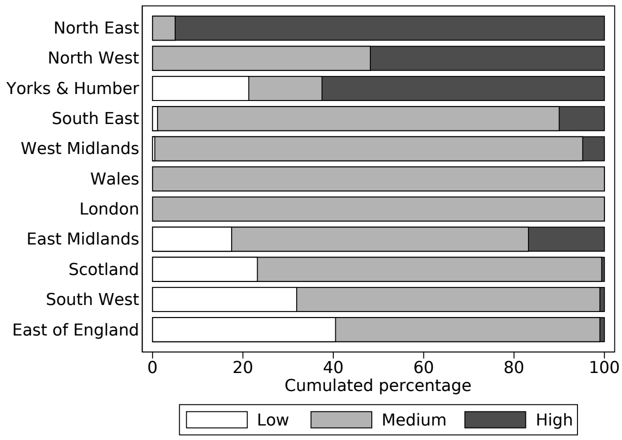


Figure 3. Percent of families living in low, normal or high lead concentration areas by geographic region

eas with lead concentration levels falling one standard deviation below or above the MCS sample mean have been defined as "low" (13 per cent) or "high" (17 per cent) respectively. Note, however, that these are purely relative measures to illustrate potential for analysis and have no independent scientific meaning. All other areas we classified as having "normal" (70 per cent) lead concentration levels. In terms of numbers, 307 families lived in "low" lead concentration level areas, 1,974 in "normal" lead concentration level areas and 361 families in "high" lead concentration level areas. Figure 3 shows that lead concentration levels vary by region: lower lead concentration levels are associated with regions containing more rural areas, and higher lead concentration levels with the (traditionally) industrial North.

Coverage, both in terms of geography and different degrees of environmental lead concentration thus seemed to provide a rich resource for analysis of geographical variation and to meet the initial needs of the study. The second key area of interest in terms of coverage was the extent to which the responding sample was representative across families and, crucially, provided sufficient coverage of diverse family and individual characteristics. Such different family and individual level characteristics are relevant not just for the study of lead exposure, but also for analyses that involve the exploration of other exposures and the nutritional information embedded in milk teeth.

To explore differences in response, we focus on family-level analysis of singleton children or the first child of families with twins or triplets. Table A1 in the appendix illustrates the extent to which, among those responding to MCS4, those who supplied a tooth differed from those who did not and from the overall sample. It details the overall distribution of participation history, and a number of biological, socio-economic, behavioural and environmental characteristics of MCS4 families, followed by the distribution of each characteristic by whether a tooth was returned or not. The top panel of Table A1 shows that, propensity to respond to the tooth collection was linked to overall participation history. This aligns with our expectations and emphasises the ways in which more "compliant" or engaged respondents are more likely to participate in biomarker collection. While more than four in five MCS4 families had participated in all four rounds of data collection, over 90 per cent of those returning a shed milk tooth had complete participation records.

We then turn to consider the extent to which tooth return was associated with particular family characteristics. The characteristics were selected partly on the basis that they are those which are associated with response to the survey overall. In addition, many of them are highly relevant to research questions involving analysis of teeth, such as breastfeeding, socio-economic position, area, and parental health status.

All characteristics in Table A1, with the exception of UK country, were significantly associated with a participating MCS4 family also returning one of their child's shed milk teeth in the directions indicated by the distributions. In summary, the families who returned one of their child's teeth were more likely to consist of an older mother who breastfed, to be two natural parents who were both in work and to have a higher socio-economic position – in terms of home ownership, high level qualifications and occupation status. They were also more likely to report good health and to live in less deprived areas or advantaged wards. However, despite these differences, the distribution of the returned teeth sample compared to the overall MCS4 sample are not dramatically different, even though only one in five families responded.

In addition, we see that in terms of sample sizes, even where categories are relatively small and response is skewed between those who did and did not supply a tooth, there are analytically viable numbers of teeth. For example, more chaotic households have in the past been associated with higher blood levels of lead, and while those who strongly agree that the home is disorganised are both a small group overall and are under-represented among those supplying a tooth there are nevertheless 94 respondents in this category who did supply a tooth. For addressing the research questions that the combination of rich social science data and children's shed milk teeth render possible, it is arguably the numbers available for the selected characteristics of interest, rather than representativeness *per se* that is the key issue.

4 Conclusions and discussion

The collection of biomeasures in existing social surveys can transform them into biosocial surveys, facilitating interdisciplinary research and expanding the potential for analysis of health using objective measures. However, biomeasures can often be expensive to collect, relatively intrusive or demanding for respondents, resulting in lower response rates than for questionnaire data. In this paper, we have discussed the potential for enhancing national social surveys that include families with children through the postal collection of exfoliated milk teeth. Shed milk teeth have the potential to provide insights into children's early environment, including in utero, their nutrition, dental care use and maternal health. The wide geographical coverage of many social surveys, alongside the wide social spectrum typically captured and the range of relevant covariates, offers rich potential for developing research agendas on early life experiences and their possible long-term consequences. While, unlike some biomeasures, teeth are a depletable resource, analysis typically works with small numbers, meaning that a large-scale collection can serve a large number of research projects under appropriate access conditions.

We reported on the postal collection of exfoliated milk teeth of participants in the Millennium Cohort Study, a longitudinal study of children born in 2000-2001. The teeth were collected when the children were aged between 7 and 10 years old and provide the largest collection of milk teeth carried out in the UK to date. Moreover, the collection was conducted at minimal cost. While longitudinal studies tend to increase response rates in biomarker collection compared to cross-sectional studies, due to the greater investment and 'compliance' or respondents to such studies, the response rate was, however, still low at around 21 per cent. This might raise concerns about the extent to which the responding sample represents those with particular characteristics of relevance for analysis and the research questions that shed milk teeth can help social surveys to address. We found that those families who returned milk teeth were skewed in predictable directions, with more advantaged and those in more stable family circumstances more likely to respond. Nevertheless, the coverage of returned teeth across those characteristics likely to be of interest for research involving analysis of teeth was shown to provide sufficient *numbers* to allow meaningful analysis across regions, family socio-economic circumstances, breastfeeding, child birth weight etc. Hence, where prevalence estimates are not in themselves the primary interest, the low and somewhat skewed response rates may still allow meaningful analysis. The large numeric base of a nationally representative social survey provides a good starting point for analysis of questions relating to in utero environmental exposure, maternal nutrition and child diet, and their longterm consequences.

Nevertheless, there are a number of ways in which collection rates might be improved, and quality of information on the teeth provided enhanced, without adding excessively to the costs. These could include further rounds of reminders for non-responding families; greater emphasis at the point of the main data collection, including, potentially, interviewer 'placement' and guidance on the tooth chart; and provision of feedback on findings from existing studies or those directly using those teeth returned relatively early. Future studies could helpfully build some of more of these approaches into the design of collection. Understanding more about the motivation of respondents with initial piloting, or through follow-up of responders and non-responders could also shed further light on how to maximise response.

Overall, as understanding of what teeth can tells us about health, development and early environment increases, and the costs of advanced analysis using mass spectrometry decrease, the postal collection of milk teeth offers a potentially cheap and easy win for social surveys to shed greater light on the interplay of social, contextual and biological factors in child, adolescent and adult outcomes.

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Appendix

(Appendix table on next page)

Table A1
Weighted percentages and sample sizes for all families in MCS4 by whether returned a tooth or not

	Overall		No tooth returned		Tooth returned	
	abs.	%	abs.	%	abs.	%
All MCS4 families	**13857**	**100**	**10924**	**79.0**	**2933**	**21.0**
MCS Participation: n sweeps						
Two sweeps	644	4.6	610	5.5	34	1.2
Three sweeps	1497	11.1	1273	12.0	224	7.7
All four sweeps	11716	84.3	9041	82.5	2675	91.1
Biological						
Gender						
Male	7029	51.4	5618	52.2	1411	48.3
Female	6828	48.6	5306	47.8	1522	51.7
Ethnicity						
White	11591	85.4	9013	84.4	1578	89.0
Mix	383	3.3	301	3.3	82	3.2
Indian	343	1.9	284	2.0	59	1.8
Pakistani/Bangladesh	888	4.7	780	5.3	108	2.5
Black British	458	3.3	390	3.6	68	2.2
Other	185	1.3	149	1.4	36	1.3
Age mother at birth						
Teenager	994	8.8	894	10.0	100	4.0
20-29	6024	45.9	4991	48.2	1033	37.2
30-39	6036	43.3	4415	40.0	1621	55.7
40+	300	2.0	210	1.7	90	3.2
Behavioral						
Ever breastfed						
Yes	9288	68.3	7055	65.8	2233	77.8
No	4049	31.7	3439	34.2	610	22.2
Regular bedtime						
Never	533	3.7	458	4.1	75	2.3
Sometimes	798	5.5	654	5.7	144	4.8
Usually	4248	31.1	3281	30.5	967	33.4
Always	8204	59.7	6462	59.8	1742	59.4
Disorganised home						
Strongly agree	608	4.9	514	5.3	94	3.6
Agree	1442	11.0	1181	11.5	261	9.0
Neither	2210	16.3	1807	17.1	403	13.5
Disagree	6375	45.5	4965	44.9	1410	47.5
Strongly disagree	3116	22.4	2360	21.3	756	26.5
Longstanding illness						
Yes, limiting	910	6.8	749	7.1	161	5.8
Yes, longstanding	1670	12.3	1311	12.2	359	12.7
No illness	11194	80.9	8787	80.7	2407	81.4

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	Overall		No tooth returned		Tooth returned	
	abs.	%	abs.	%	abs.	%
All MCS4 families	**13857**	**100**	**10924**	**79.0**	**2933**	**21.0**
General health						
Excellent	8164	59.8	6325	58.8	1839	63.3
Very/good	5182	37.2	4153	37.9	1027	34.7
Fair/poor	437	3.0	375	3.3	62	2.0
Environmental						
Ward type						
Advantaged	5773	56.7	4259	54.1	1514	66.5
Disadvantaged	6410	37.0	5262	39.1	1148	29.0
Ethnic	1674	6.3	1403	6.7	271	4.4
UK country						
England	8887	81.6	6968	81.3	1919	82.8
Wales	1972	5.1	1591	5.2	381	4.6
Scotland	1622	9.3	1267	9.4	355	8.8
Northern Ireland	1376	4.0	1098	4.1	278	3.9
Govt. Office Region						
North East	402	3.7	333	3.8	69	2.9
North West	1134	10.7	912	11.0	222	9.3
Yorks & Humberside	1020	8.8	837	9.2	183	7.5
East Midlands	741	7.2	550	6.8	191	9.1
West Midlands	1022	8.0	802	7.9	220	8.3
East of England	999	9.5	760	9.2	239	10.5
London	1416	11.1	1140	11.3	276	10.1
South East	1379	14.5	1050	14.1	329	16.0
South West	772	8.1	584	7.9	188	9.1
Wales	1972	5.1	1591	5.2	381	4.6
Scotland	1622	9.3	1267	9.4	355	8.8
Northern Ireland	1376	4.0	1098	4.1	278	3.9
At same address						
Yes	12494	88.6	9825	88.3	2669	89.7
No	1362	11.4	1098	11.7	264	10.3
Index Deprivation						
Most deprived 10%	1885	11.9	1646	13.2	239	6.8
20%	1729	10.6	1482	11.7	247	6.6
30%	1553	10.0	1262	10.3	291	8.8
40%	1323	8.9	1049	9.0	274	8.2
50%	1249	9.7	976	9.7	273	9.7
60%	1206	9.6	923	9.4	283	10.4

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	Overall		No tooth returned		Tooth returned	
	abs.	%	abs.	%	abs.	%
All MCS4 families	**13857**	**100**	**10924**	**79.0**	**2933**	**21.0**
70%	1157	9.7	863	9.2	294	11.5
80%	1131	9.2	846	8.9	285	10.5
90%	1243	9.7	904	8.9	339	12.6
Most un-deprived 10%	1379	10.8	973	9.7	406	15.0
Social						
Housing tenure						
Own	9122	63.0	6839	59.6	2283	75.8
Rent (social)	3129	24.7	2702	27.2	427	15.6
Rent (private)	1188	9.7	1013	10.4	175	7.0
Other	325	2.5	283	2.8	42	1.5
Income (OECD)						
> 60% median	9675	70.8	7359	68.3	2316	80.4
< 60% median	4162	29.2	3549	31.79	613	19.6
Highest qualification						
None	1015	7.4	922	8.5	93	3.3
Overseas	297	2.0	255	2.1	42	1.5
NVQ1	667	5.3	573	5.7	94	3.6
NVQ2	3050	23.3	2510	24.5	540	18.8
NVQ3	2233	15.9	1812	16.4	421	14.1
NVQ4	4847	34.3	3625	32.2	1222	42.1
NVQ5	1747	11.7	1226	10.5	521	16.5
Highest SES (current job)						
Prof & Managerial	3250	24.2	2345	22.1	905	32.1
Intermediate	1373	10.4	1033	10.0	340	11.7
Sm emp & Self emp	1702	12.9	1293	12.4	409	14.7
Lo sup & technical	1058	7.9	826	8.0	232	7.7
Semi-routine & routine	3611	26.9	2921	27.8	690	23.6
Not in work	2240	17.8	1962	19.8	278	10.2
Parental working status						
Both in work	6797	48.0	5061	45.3	1736	58.4
1 of 2 in work	3386	24.0	2712	24.3	674	23.1
Single parent in work	1425	10.9	1181	11.6	244	8.5
Both not in work	747	5.3	636	5.8	111	3.3
Single parent not in work	1493	11.7	1326	13.1	167	6.7

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	Overall		No tooth returned		Tooth returned	
	abs.	%	abs.	%	abs.	%
All MCS4 families	**13857**	**100**	**10924**	**79.0**	**2933**	**21.0**
Household type						
Both natural parents	9992	69.3	7625	66.8	2367	78.9
Two parent/guardians	940	8.0	786	8.5	154	5.9
Single parent	2925	22.7	2513	24.7	412	15.2
Number of children						
1	1771	13.1	1408	13.4	363	12.1
2	6244	46.0	4822	45.0	1422	49.7
3	3766	26.9	2954	26.7	812	27.6
4	1409	9.6	1153	10.0	256	8.2
5	667	4.3	587	4.9	80	2.4
Language spoken at home						
English only	11946	89.8	9327	89.3	2619	91.9
English + other	1812	9.6	1513	10.2	299	7.5
Other only	99	0.5	84	0.5	15	0.5