PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

Exploratory Data Analysis of Three Sexual Behaviour Surveys: Implications for HIV-1 Transmission in the U.K.

S. M. Blower

Phil. Trans. R. Soc. Lond. B 1993 **339**, 33-51
doi: 10.1098/rstb.1993.0003

Exploratory data analysis of three sexual behaviour surveys: implications for HIV-1 transmission in the U.K.

S. M. BLOWER

Biomedical & Environmental Health Sciences, School of Public Health, University of California, Berkeley, California 94720, U.S.A.

CONTENTS

SUMMARY

Recently, the number of European and North American heterosexually transmitted AIDS cases has begun to increase. It appears that injecting drug users may be acting as an important infection source for heterosexual transmission, and that the HIV-1 epidemic may be slowly diffusing out into the general population. Therefore, the question arises, as to whether there will be an extensive heterosexually transmitted epidemic in Europe or North America. The possibility of such an epidemic occurring depends upon three factors: sexual mixing patterns, the prevalence and the distribution of specific risk factors, and changes in risk behaviours. To assess the potential for an extensive sustained heterosexually transmitted epidemic it is necessary to estimate these three factors by conducting large-scale linked behavioural and seroprevalence surveys. Unfortunately, such surveys have yet to be conducted in any country. However, a limited amount of sexual behaviour data are available from three small studies that have been conducted in the U.K. Although each of the studies suffers from methodological imperfections, together they may be used as the basis for a preliminary assessment of the potential effects of heterosexual transmission in the U.K. In this paper I discuss the results from an exploratory analysis of these data; the results are organized into five sections: (i) assessment of the prevalence and distribution of specific risk behaviours; (ii) determination of covariates of risk behaviours (and hence characterization of the subgroups that may be at risk); (iii) assessment of age-dependent sexual mixing patterns; (iv) assessment of sexual behaviour changes; and (v) calculation of epidemiological parameters. The validity and the reliability of the data from the three studies are assessed. The analysis suggests that it is possible that a heterosexually transmitted HIV-1 epidemic could occur in the U.K. Hence, it is essential to conduct longitudinal surveys that collect linked seroprevalence and behavioural data.

Phil. Trans. R. Soc. Lond. B (1993) **339,** 33–51
Printed in Great Britain

1. INTRODUCTION

By the mid-1980s, it was recognized that heterosexual intercourse is the dominant mode of transmission of the human immunodeficiency virus type 1 (HIV-1) in Africa (Piot *et al.* 1988; Quinn *et al.* 1986). In contrast, the vast majority of European and North American AIDS cases have acquired HIV-1 through homosexual transmission or through the practise of sharing injecting drug-using equipment, and heterosexual transmission has been of little epidemiological importance. The reason for the geographic differences in transmission patterns remains unknown, but may reflect the geographic variation in the prevalence and distribution of certain risk factors. Recently, the number of European and North American heterosexually transmitted AIDS cases has begun to increase substantially (France *et al.* 1988; Haverkos & Edelman 1988; Holmes *et al.* 1990). Most of these AIDS cases have been reported in areas that contain large numbers of injecting drug users (IDU) and many of these recent cases have reported having heterosexual intercourse with IDU (Allain 1986; Fischl *et al.* 1988; Holmes *et al.* 1990; Jones *et al.* 1985; Redfield *et al.* 1985). Hence, it appears that IDU may be acting as an importanct infection source, and that the epidemic may be slowly diffusing out into the general population. The question arises, as to whether there will be an extensive sustained heterosexually transmitted epidemic in Europe or North America. The possibility of such as epidemic occurring depends upon three factors: sexual mixing patterns (especially the degree of sexual mixing that occurs between the IDU community and the rest of the heterosexual population (Blower 1990)), the prevalence and the distribution of a wide variety of demographic, biological and behavioural risk factors in the general population (Blower *et al.* 1990) and both current and future risk behaviour changes. In order to assess the potential for an extensive sustained heterosexually transmitted epidemic it is necessary to estimate these three factors by conducting large-scale linked behavioural and seroprevalence surveys. Such surveys would enable an individual's risk behaviour to be linked to their HIV-1 serostatus. Unfortunately, such large-scale surveys have yet to be conducted in any country.

However, a limited amount of sexual behaviour data are available from three small studies that have been conducted in the U.K. Although each of the three studies suffer from methodological imperfections, together they may be used as the basis for a preliminary assessment of the potential effects of heterosexual transmission in the U.K. In this paper I discuss the results from an exploratory analysis of these data. This analysis was performed to search for qualitative patterns and trends in available data, and not to provide quantitative estimates of any of the risk behaviours. The main objective of this paper is to present a preliminary assessment of the potential for a heterosexual HIV-1 epidemic in the general population in the U.K.; therefore I: (i) assess the prevalence and distribution of specific risk behaviours; (ii) determine covariates of risk behaviours (and hence characterize the subgroups that may be at risk); (iii) assess age-dependent sexual mixing patterns; (iv) assess sexual behaviour changes; and (v) calculate epidemiological parameters. Throughout the paper the reliability (reproducibility) of the results from the three studies are assessed by comparing: the qualitative patterns for specific variables, the frequency distributions of specific variables, and the summary statistics for these distributions. The remainder of the paper is organized into three sections. I begin with a methodology section; this section contains a brief description of the three sampling methodologies, a summary of the demographic characteristics of each sample and a discussion of the statistical analyses. The next section presents results summarized under the following headings: prevalence and distribution of risk behaviours, characterization of at-risk subgroups, age-dependent sexual mixing patterns, sexual behaviour changes and epidemiological parameters. I conclude with a discussion of the implications of the results for the potential for an extensive sustained heterosexual epidemic in the U.K.

2. METHODOLOGY

(*a*) *Sampling methodologies*

The three sexual behaviour studies that are compared in this analysis are the Gallup, the Harris and the British Market Research Board (BMRB) study. The Gallup study, carried out in the autumn of 1987, was a pilot survey to determine the feasibility of obtaining sexual behaviour data from a large random sample of the adult population of England and Wales (Blower *et al.* 1990; Johnson *et al.* 1989). A multi-stage sampling procedure was used to obtain 780 participants (337 males and 443 females) aged between 16 and 64 years. Participants were contacted by house-to-house interviewers and asked to participate, sexual behaviour data were collected by self-administered questionnaires. Respondents were asked to report their exact number of sex partners over seven time intervals (the previous 4 weeks, 3 months, 6 months, 1 year, 2 years, 5 years and lifetime). Participants were asked to list, for their last six partnerships, the month and the year that the partnership began and ended, and their age and the partner's age at the beginning of the partnership. These partnership data were used to assess partnership duration and the age-dependent sexual mixing patterns. The sampling strategy, data collection methodology, response rate, further data analysis and the limitations of the study have been described in detail elsewhere (Blower *et al.* 1990; Johnson *et al.* 1989).

The Harris survey was carried out in 1986 by quota sampling. Data were collected from 863 individuals (440 women and 423 men) aged between 18 and 44 years old. Respondents were asked to report whether they had one or more sex partners in the past 5 years. Respondents who reported more than one partner were asked to specify the exact number (and the gender) of their sex partners over the previous 1 month, 2 months, 1 year and 5 years. These respondents were also asked questions about the frequency of certain sexual activities (oral and anal intercourse) and about recent changes in their sexual behaviour.

The BMRB has been collecting data on sexual behaviour approximately every 3 months since February 1986 (BMRB 1987). Every sampling wave consists of the collection of data from two different groups: the general public and homosexuals. In this analysis I examined the data generated from the first four sampling waves (i.e. data collected between February 1986 and February 1987). The general public samples were collected by a mixture of stratified random sampling and quota methods. The homosexual samples were collected by interviewing clientele in homosexual pubs and clubs; for further details of the sampling methodology see BMRB (1987). Both the general population and the homosexual group were sampled over the age range 18–64 year olds. Respondents were asked to report the gender and the number of their sex partners in the previous 12 months. Heterosexuals who reported more than one opposite sex partner and homosexuals who reported at least one same sex partner in this time period were asked specific questions on sexual practices; these respondents were also asked to state the number of sexual partners over the previous two time intervals (3 months, 12 months). Unfortunately, the number of reported sex partners was recorded as categories rather than as exact numbers; whilst it is possible to use an approximation formula to calculate means and variances from categorical data, the values of the estimated means and variances are dependent upon the assumption that is made concerning the distribution of the actual values within each of the defined categories (Kahn & Sempos 1989). Rather than assume specific distributions and make potentially misleading comparisons among the three surveys, I chose not to calculate means and variances for the BMRB sexual partner data.

(*b*) *Demographic characteristics of the samples of the three studies*

The similarity of the composition of the samples of the studies can be assessed by comparing their demographic characteristics (see table 1). The degree to which any of the samples represent the general population can be assessed by comparing the demographic characteristics of the samples with census statistics of the demographic characteristics of the general population (see table 1). The sex ratio in the BMRB samples are male-biased, because males were deliberately oversampled, as the BMRB perceived males to be at a greater risk of acquiring HIV-1 than females. The sex ratios in the Gallup and the Harris surveys are not significantly different and are similar to the sex ratio in the general population. The three surveys differ slightly in their age composition. In the BMRB samples 18–34 year olds are over-represented (these younger age classes had been deliberately oversampled), as the BMRB perceived younger individuals to be at a greater risk of acquiring HIV-1 than older individuals. The Harris survey differs from the other studies as the age composition is skewed towards the younger age classes. The Gallup survey is the most similar to that of the general population. The heterosexual studies do not differ significantly in their socio-economic class distributions. The sampled socio-economic class composition could not be compared with the socio-economic class composition of the general population, because the appropriate data were not available. The three studies differ in their marital

Table 1. *Demographic characteristics of the samples in the three sexual behaviour studies*

(The following codes are used: M = males, F = females, BMRB (*x*) = BMRB (wave number), 1 = married/living as married, 2 = single, 3 = separated/widowed/divorced, * = age-class contains 16–24 year olds.)

survey	sample size	sex (%)		age-class (%)					socio-economic class (%)				marital status (%)		
		M	F	18–24	25–34	35–44	45–54	55–64	AB	C1	C2	DE	1	2	3
heterosexual samples															
Harris	863	51	49	31	35	34	0	0	16	28	30	26	46	40	14
Gallup	780	43	57	19*	26	23	16	16	21	23	31	25	67	23	10
BMRB (1)	697	76	24	26	33	18	11	13	16	22	32	31	65	30	5
BMRB (2)	702	76	24	28	30	21	11	11	17	27	25	31	65	31	4
BMRB (3)	786	65	35	25	24	19	10	22	14	24	31	31	59	34	6
BMRB (4)	787	67	33	25	25	17	12	21	13	26	28	33	61	33	6
homosexual samples															
BMRB (1)	156	100	0	42	37	15	5	1	15	38	21	26	11	86	3
BMRB (2)	298	100	0	42	41	13	3	1	12	43	17	28	6	92	1
BMRB (3)	283	100	0	42	35	15	6	2	13	42	17	28	11	81	8
BMRB (4)	251	100	0	41	38	17	2	1	16	44	13	28	14	79	7

census statistics	sex (%)		age-class (%)					marital status (%)		
	M	F	15–24	25–34	35–44	45–54	55–64	1	2	3
	49	51	24	22	21	17	16	48	41	11

status composition. The Harris survey has slightly more single individuals that were married or living as married than the other two surveys; the Harris marital status distribution was the most similar to the marital status distribution in the general population. The BMRB heterosexual surveys have slightly more singles and fewer separated, widowed or divorced individuals than the Gallup survey. The demographic characteristics of the BMRB heterosexual sample differ from those of the homosexual sample. The homosexual samples are composed of individuals that are younger, of a higher socio-economic class and more likely to be single than individuals in the heterosexual sample.

(*c*) *Statistical analyses*

The three data sets are far from perfect, and there are many problems due to item non-response bias. Therefore, I performed an exploratory analysis of the three data sets, searching for qualitative patterns and trends rather than quantitatively estimating any of the risk behaviours. Gender-specific frequency distributions of the number of sexual partners per unit time were derived, and simple descriptive statistics were calculated for these distributions. As most of the variables in these studies were nonnormally distributed, non-parametric methods were used to analyse these data. Log-linear models were used to search for qualitative patterns and to identify associations among variables; the models were stratified by gender and unweighted. Odds ratios and confidence intervals are not presented because specific models were not fitted.

The Gallup partnership data were used to estimate age-dependent sexual mixing patterns, that is, to identify 'Who has sex with whom'. Three-dimensional histograms were derived by stratifying the partnership data on the basis of gender, and then grouping partnerships into five year age–cohort classes (age is the age of both partners at the beginning of the sexual partnership); the percentage of sexual partnerships that each age–cohort had with each other age–cohort class of the opposite sex was then calculated. The Gallup partnership data were also analysed to assess the relationship between the number of sex partners per unit time and the probability of concurrent partnerships. The percentage of heterosexuals (with at least one sexual partner during their lifetime) reporting at least one concurrent partnership was calculated. The date (month and year) on which sexual partnerships had begun and had ended had been obtained from respondents; any sexual partnership that occurred in the same month and year was classified as a concurrent partnership, partnerships that did not overlap were classified as serially monogamous. Gender-specific frequency distributions for the proportion of heterosexuals who reported at least one concurrent partnership stratified by (i) the reported number of lifetime partners and (ii) cohort–age were derived. The Gallup partnership data were further analysed to assess the relationship between the number of sex partners per unit time and partnership duration; any partnership that began and ended in the same month was classified as less than a month, all other partnerships were assumed to begin and end in mid month. Gender-specific frequency distributions of heterosexual partnership duration stratified by (i) the reported number of lifetime sexual partners and (ii) the age–cohort were derived.

Two epidemiological parameters, the basic reproductive rate and the initial doubling time of the epidemic, were calculated. The basic reproductive rate of the virus (R_o) is defined as the average number of secondary infections generated when an infectious individual is introduced into a population of susceptibles (Macdonald 1952). In this analysis the value of the basic reproductive rate of HIV-1 is used as a simple indicator variable to identify whether the virus is likely to spread extensively in the population ($R_o > 1$) or not ($R_o < 1$). Although the biological definition of both the basis reproductive rate and the initial doubling time are independent of the epidemiological mathematical model, the mathematical definitions of these two parameters are model dependent. The basic reproductive rate was estimated from:

$$R_o = (\beta_1 C_1 \beta_2 C_2)^{1/2}/v, \quad (1)$$

where

β_1 = the average heterosexual transmission efficiency per partnership from a male to a female;
C_1 = the 'effective average' rate of sex partner change in heterosexual females;
β_2 = the average heterosexual transmission efficiency per partnership from a female to a male;
C_2 = the 'effective average' rate of sex partner change in heterosexual males;
$1/v$ = average duration of infectiousness (in years) within the incubation period.

The definition of R_o in equation (1) is approximate and is derived from a simple deterministic model for heterosexual transmission; the 'effective average' rate of sex partner change is a weighted average, calculated by adding the mean rate of sex partner change to the variance to mean ratio (Anderson & May 1988*a*; May & Anderson 1987).

The Gallup and the Harris surveys had collected data on the reported number of sex partners in different time intervals and not on the rate of change of sex partners; hence, gender-specific annual rates of change of sex partners were estimated by calculating the differences between the total reported number of sex partners in the different time periods. For example, if a person reported five sex partners in the past 2 years and two sex partners in the past year, the annual rate of change of sex partners (over this time interval) is three sex partners per year. Difference calculations were performed for the entire sample to generate gender-specific frequency distributions, means and variances for the rate of change of sex partners. Three gender-specific annual rates of change of sex partners were calculated from the Gallup data, by using the calculated difference in the number of sexual partners for: 5 years and 1 year, 5 years and 2 years, and 2 years and 1 year. Only one gender-specific annual rate of change of sex partners could be calculated from the Harris data, by calculating the difference in the number of sexual partners for 5 years and 1 year. Gender-specific annual rates of change of sex partners were not calculated from the BMRB data, because only categorical data had been collected.

The values of the other parameters in equation (1) can not be precisely estimated (Anderson & May 1988). To weight the calculations towards estimating minimum values of R_o, minimum estimates of all of the parameters were used. The average duration of the infectiousness within the incubation period was assumed to be 2 years, the average heterosexual transmission efficiency per partnership (male to female) was assumed to be 0.2 and the average heterosexual transmission efficiency per partnership (female to male) was assumed to be 0.1. Justification of these values is given by Anderson & May (1988*b*). The doubling time of the epidemic in the period when the virus first enters the susceptible population was calculated from equation (2) (Anderson *et al.* 1986). The doubling time will change as the epidemic progresses, as saturation effects will limit the rate of contact with susceptible sex partners.

$$t_d = ((\ln 2)\ 1/v)/(R_o - 1). \qquad (2)$$

3. RESULTS

To predict whether an extensive sustained heterosexually transmitted HIV-1 epidemic will occur in the U.K. it is necessary to estimate: the prevalence and the distribution of the risk behaviours in the general population, sexual mixing patterns, and risk behavioural changes.

(*a*) *Prevalence and distribution of risk behaviours*

The data were analysed to assess the prevalence and distribution of three risk behaviours: number of sex partners per unit time, anal intercourse and oral intercourse. These three factors have previously been identified as risk factors associated with heterosexual transmission of HIV-1 in other studies (Cameron *et al.* 1989; European Study Group 1989; Fischl *et al.* 1987; Johnson & Laga 1988; Marmor *et al.* 1990; Padian *et al.* 1988; Padian 1990*a*; Rozenbaum *et al.* 1988; Winkelstein *et al.* 1987).

(i) *Number of sex partners in the previous 12 months*

Gender-specific frequency distributions of the number of sex partners per year were derived from the Gallup and the BMRB surveys. The distributions for heterosexuals are shown in figure 1. The frequency histograms are very similar for the two surveys; the majority of heterosexuals report only one partner in the previous year, but a small minority report two or more sex partners (see figure 1). Gender differences in the reported number of sex partners are apparent in both studies; females report fewer sex partners per unit time than males. This gender difference could be due to many reasons; for example, the samples are small and therefore the samples may not be representative of both sexes, the small proportion of sexually active females may have been undersampled, or males may have over-reported and/or females under-reported their true number of sex partners.

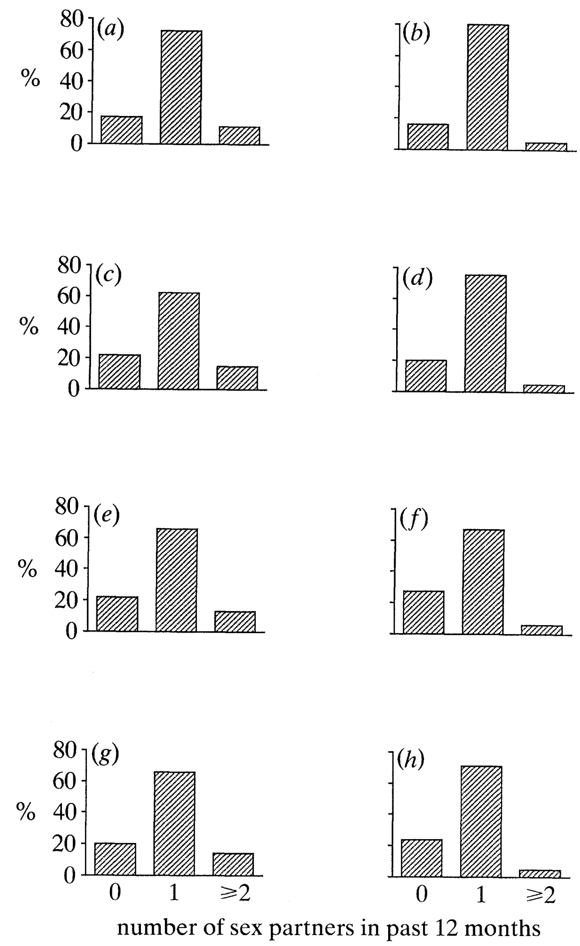

Figure 1. Frequency distributions: the proportion of heterosexuals is plotted on the *y*-axis, the reported number of opposite sex partners in the previous 12 months is plotted on the *x*-axis (*a,c,e,g*: males; *b,d,f,h*: females) in the Gallup (*a,b*) and the BMRB (*c,d*: wave 2; *e,f*: wave 3; *g,h*: wave 4) studies. Sample sizes: Gallup males = 292; Gallup females = 382; BMRB males (waves 2, 3, 4) = 514, 493, 516; BMRB females (waves 2, 3, 4) = 165, 264, 252.

Frequency distributions for the number of sex partners per year reported by homosexuals (BMRB data) are shown in figure 2; distributions for waves 2, 3 and 4 are shown, wave 1 is not included because the wording of the question on the number of sex partners per unit time changed considerably between waves 1 and 2. Figure 2*a–f* shows that the majority of homosexuals had few opposite sex partners, but at least two same sex partners in the previous 12 months. The derived histograms can be used to compare homosexual and heterosexual behaviour. Homosexuals tend to be as sexually active (when defined by the number of opposite sex partners per unit time) as heterosexuals (compare figure 1*a–h* and figure 2*a–c*); however, homosexuals tend to be more sexually active (when defined by the number of same sex partners per unit time) than heterosexuals (compare figure 1*a–h* with figure 2*d–f*). Log-linear modelling identified a

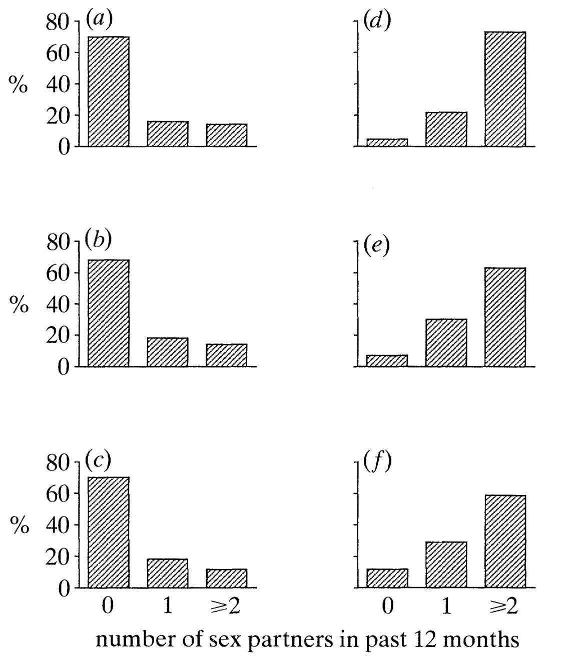

Figure 2. Frequency distributions: the proportion of homosexuals is plotted on the y-axis, the reported number of opposite sex (a–c) and same sex partners (d–f) in the previous twelve months from the BMRB data is plotted on the x-axis (a,d: wave 2 ($n = 288$); b,c wave 3 ($n = 283$); c,f: wave 4 ($n = 250$)).

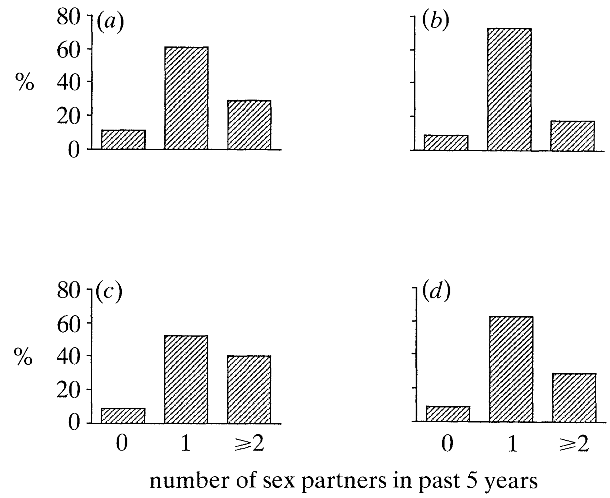

Figure 3. Frequency distributions: the proportion of heterosexuals is plotted on the y-axis, the reported number of opposite sex partners in the previous five years is plotted on the x-axis (a,c: males; b,d: females); for the Gallup (a: $n = 294$; b: $n = 383$) and the Harris (c: $n = 418$; d: $n = 388$) studies.

significant positive association ($p < 0.05$) in the homosexual sample between the reported number of opposite sex partners and the reported number of same sex partners in the past 12 months; those men who reported a high number of opposite sex partners tended to report a high number of same sex partners.

(ii) *Number of sex partners in the previous 5 years*

Gender-specific frequency distributions for heterosexuals for the reported number of sex partners in the previous 5 years were derived from the Gallup and the Harris surveys; the distributions are shown in figure 3, gender-differences are again apparent. The distributions in figure 3 show the same pattern as the distributions in figure 1; however, as these data are the reported number of sex partners over the previous five years rather than the previous year, the proportion of heterosexuals reporting two or more sex partners is greater than the proportion in the histograms in figure 1. The frequency histograms derived from the Gallup and Harris surveys are very similar (see figure 3); although the proportion reporting two or more partners is greater in the Harris survey. Because the difference in the proportions may have been due to differences in the age structure of the two samples (which are apparent in table 1), age stratified means and variances for the number of sex partners in the previous five years were calculated (see table 2). As can be seen in table 2, gender-differences are again apparent, the age-stratified means calculated from the two surveys are similar, there exists high variability in the reported number of sex partners within age classes, and both the mean and the variance in the number of reported sex partners decreases with increasing age. These results suggest that the differences in the frequency histograms in figure 3 may be due to the greater proportion of older individuals that are sampled in the Gallup survey in comparison with the Harris survey.

(iii) *Prevalence of anal and oral intercourse*

The BMRB data suggest that of heterosexual men (who reported more than one female partner in the previous twelve months) $9.3 \pm 0.9\%$ had anal intercourse with a woman in this time period, and $60.8 \pm 2.2\%$ had oral intercourse. Prevalence calculations from the Harris data are similar: 8% of male and 10% of female heterosexuals (who reported at least one sexual partner in the previous five years) had ever had anal intercourse and 1% of male and female heterosexuals often have anal intercourse. In contrast to anal intercourse, 73% of men and 68% women had ever had oral intercourse and 1% often have oral intercourse. Behavioural differences among heterosexuals, bisexuals and homósexuals are also indicated by the BMRB data. Bisexual males (homosexuals who reported more than one female partner in the previous 12 months) appear similar to heterosexual males with respect to anal and oral intercourse; only $9.5 \pm 2.0\%$ of bisexuals had anal intercourse with a woman and $47 \pm 5.9\%$ of bisexuals had oral intercourse in the previous 12 months. Homosexual males (who reported sex with at least one male in the previous 12 months) appear more sexually active than heterosexual males; $50.8 \pm 6.8\%$ of homosexuals had active unprotected anal sex with a man, $35 \pm 3.2\%$ had passive unprotected anal sex with a man and $79.5 \pm 1.5\%$ had oral sex with man in the previous 12 months.

Table 2. *Age-stratified summary statistics (mean and variance (var)) for the reported number of sexual partners in the previous 5 years for heterosexuals sampled in the Harris and the Gallup surveys*

(Sample sizes: Harris males = 397, Harris females = 372; Gallup males = 294, Gallup females = 383.)

	Gallup					Harris			
	males		females			males		females	
age	mean	var	mean	var	age	mean	var	mean	var
16–24	5.6	213.1	1.8	3.0	18–24	5.0	96.5	2.2	10.3
25–34	3.0	18.6	1.6	2.9	25–34	3.7	91.9	1.2	3.1
35–44	2.5	38.7	1.2	0.4	35–44	2.6	31.0	1.3	1.7
45–54	1.2	0.6	0.9	0.1					
55–64	1.2	2.0	0.7	0.2	totals	3.7	72.5	1.8	4.8
totals	2.9	61.45	1.3	1.64					

(*b*) *Characterization of potentially at-risk subgroups*

The previous analyses identified the sizes of the potentially at-risk groups (i.e. the proportion of the general population that have high numbers of sex partners per unit time). Further analyses were performed to assess how the number of sex partners per unit time was related to: demographic variables (marital status and socio-economic class), the probability of concurrent partnerships, the duration of sexual partnerships and the frequency of oral anal intercourse.

(i) *Demographic variables*

Loglinear models revealed significant associations between the number of sexual partners and marital status for both sexes and all time periods in the three studies (Gallup survey, males and females: $p \ll 0.001$; Harris survey, males and females: $p < 0.05$; BMRB surveys, male and female heterosexuals, and homosexuals $p < 0.05$). The highest number of sex partners was recorded by single people. Socio-economic class (A, B, Cl, C2, D or E) was not found to be associated ($p > 0.05$) with the number of sexual partners for either sex in any time period in any of the studies.

(ii) *Concurrent partnerships*

The Gallup data were analysed to assess the relationship between the number of sex partners per unit time and the probability of concurrent partnerships. Gender-specific frequency distributions for the proportion of heterosexuals who reported at least one concurrent partnership, stratified on the basis of the number of reported lifetime sex partners, are presented in figure 4. For both sexes the more sexually active individuals (defined by their reported number of lifetime sex partners) are more likely to have a concurrent partnership than the less sexually active individuals.

(iii) *Duration of partnerships*

Gender-specific frequency distributions of heterosexual partnership duration (stratified by the reported number of lifetime sexual partners) were derived from the Gallup data. The frequency distributions for males are presented in figure 5; the patterns in females are similar, but are not shown. It can be seen that for both sexes the duration of partnerships is inversely related to the number of lifetime sex partners, people who report many sexual partners tend to have short relationships, although considerable heterogeneity is apparent.

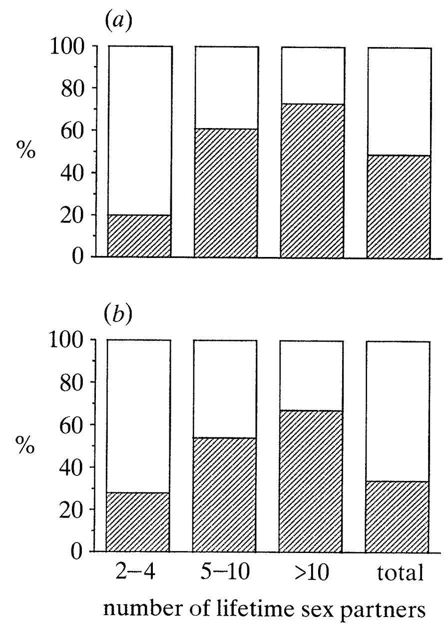

Figure 4. The gender-specific proportions of heterosexuals (*a*: males ($n = 101$); *b*: females ($n = 120$)) from the Gallup data who reported at least one concurrent sexual partnership, stratified on the basis of the number of reported lifetime sex partners. The percentages were calculated from the number of heterosexuals who reported more than one lifetime sex partner.

(iv) *Anal and oral intercourse*

The relationship between the number of sex partners per unit time and the frequency of anal and oral intercourse were explored by log-linear modelling. A significant association ($p < 0.05$) was found in the Harris data between the number of sex partners

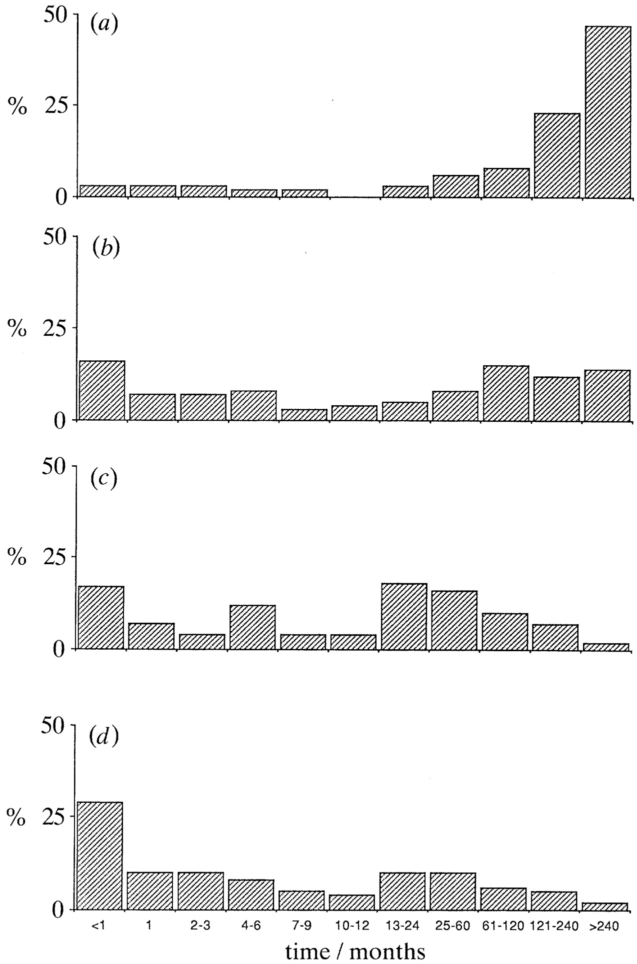

Figure 5. Frequency distributions for male heterosexuals of the duration of sexual partnerships, stratified on the basis of the number of lifetime sex partners (*a*: 1 partner; *b*: 2–4 partners; *c*: 5–10 partners; *d*: > 10 partners); calculated from the Gallup partnership data ($n = 437$). The y-axis is the proportion of sexual partnerships.

that heterosexuals reported in the previous five years and whether they engaged in oral intercourse; for both sexes those with higher number of sexual partners had oral intercourse more often than those with lower numbers of partners. A significant positive association ($p < 0.05$) was also found for both homosexuals and heterosexuals between the frequency of oral and anal intercourse. Significant positive associations ($p < 0.05$) were also found for homosexuals (who reported at least one male partner in the previous 12 months) between the frequency of passive and active anal intercourse for 3 and 12 month periods.

(*c*) *Age-dependent sexual mixing patterns*

Whether an extensive sustained heterosexually transmitted epidemic will occur depends upon the sexual mixing patterns, as well as upon the prevalence and the distribution of the risk behaviours. The Gallup partnership data were analysed to assess the age dependent mixing patterns. Three-dimensional gender-specific histograms of sexual mixing patterns (using all the partnership data) are shown in figure 6. An interesting pattern is apparent in the mixing pattern reported by males; young males (11–15 year olds) reported sexual partnerships with older women, older males (16–25 year olds) reported sexual partnerships with women in the same age–cohort group as themselves and the older males (26–45 year olds) reported sexual partnerships with progressively younger women, although considerable variability is apparent. If a large random and representative sample had been obtained, the sexual mixing pattern reported by males should match the sexual mixing pattern reported by females. However, as may be expected (due to the small sample size of the Gallup study, sampling biases, non-response or item non-response), the mixing patterns shown in figure 6 do not completely match. The sexual mixing pattern reported by the women shows that the women in this sample had sex partners that are predominantly either in the same age–cohort as, or only slightly older than, themselves.

(*d*) *Sexual behaviour changes*

In order to assess the epidemiological consequences of risk behaviour changes, these changes have to be analysed over two timescales: long term (several years) and short term (a few months to several years).

(i) *Long term behaviour changes: aging–cohort effects*

An individual's sexual behaviour is likely to be affected by both the individual's age and the cohort to which a person belongs; hence any apparent long term changes in sexual behaviour may be due to aging or cohort effects. Age and cohort effects are often confounded, because the age of a person simultaneously reflects both chronological age and the cohort to which a person belongs. Age and cohort effects can only be untangled by repeated measurements and appropriate statistical analysis. Since the relevant time series sexual behaviour data have not been collected, any associations that are found in this analysis between any variable and age are called age–cohort effects as they could be age effects, cohort effects, or a combination of both effects. The data were analysed to assess the relationship between the age–cohort effect and: (i) the reported number of sex partners per unit time; (ii) the probability of concurrent partnerships; and (iii) the duration of sexual partnerships.

Age–cohort effects and the number of sex partners per unit time

Log-linear modelling did not reveal any significant association ($p < 0.05$) in the Gallup data between the age–cohort of males and their reported number of sexual partners in any of the seven time periods; considerable heterogeneity was found in the number of sexual partners in all cohorts–age-classes (see Blower *et al.* (1990) for a graph of these data). However, this analysis did identify significant ($p < 0.001$) negative associations between the age–cohort of females and their reported number of sex partners over all measured time periods (life, 5 years, 2 years, 12 months, 6 months, 3 months and 4 weeks). Therefore younger women–cohorts tended to report a

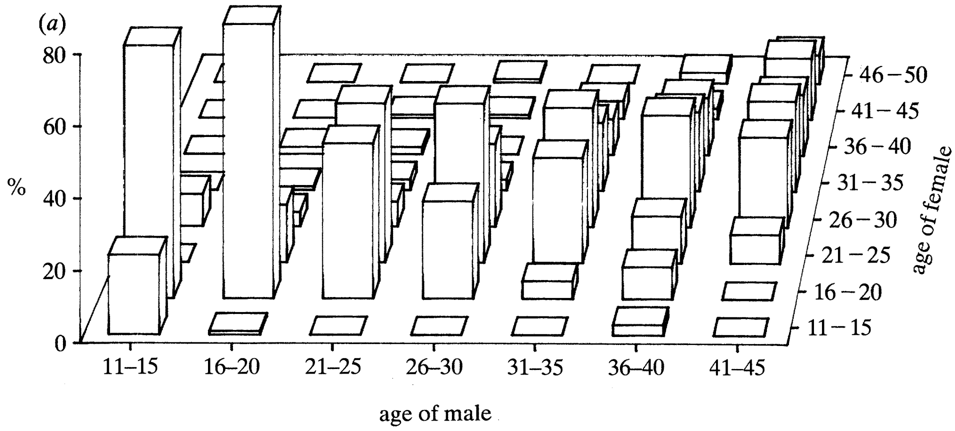

Figure 6. Sexual mixing matrices for heterosexuals (*a*: males ($n = 601$); *b*: females ($n = 630$)), calculated from the Gallup partnership data. The ages that are graphed are the ages of both partners at the beginning of the partnership.

greater number of lifetime partners than older females–female cohorts (even though the younger females had considerably fewer years than older females in which to accumulate partners). An opposite trend in the reported number of sex partners and age–cohort was found in the BMRB data; a significant negative association was found between the age–cohort of heterosexual males and their reported number of opposite sex partners in the past year, but no significant association ($p > 0.05$) was found between these two variables in the data reported by females in any of the four sampling waves. Analysis of the BMRB data also revealed a significant negative association between the age–cohort of homosexuals and their reported number of same sex partners over the same time period. Analysis of the Harris data revealed a significant negative association for both sexes (males $p < 0.001$; females $p < 0.05$) between the age–cohort of individuals and their reported number of sex partners in the past 5 years.

There are several possible explanations for the difference in results among the three studies relating the reported number of sex partners with the age–cohort. As discussed earlier, age and cohort effects are often confounded and can only be untangled by repeated sampling. If an association is found between age–cohort and the number of sexual partners in a particular time period, this association includes two components: the age effect and the cohort effect. The age and cohort effects can be most clearly seen if the number of lifetime sex partners and age–cohort are considered. An age effect will be apparent, because older males will have a greater number of sex partners than younger males (if sexual behaviour is only affected by aging) as males will either maintain a fixed number of partners or accumulate more as they age. However, a cohort effect may also be apparent if sexual behaviour has changed over the past 50 years, because members of younger cohorts may tend to be more sexually active than older cohorts. Consequently, the age and the cohort effects may act in opposition in determining the accumulated number of lifetime sex partners. An association between the number of sex partners per unit time and age–cohort will only be apparent if one effect is much stronger than the other effect. Sampling biases due to the small sample sizes may have led to different age and cohort effects in the three studies, consequently the results may be expected to differ in their findings of an age–cohort effect.

Age–cohort effects and concurrent sexual partnerships

The percentage of heterosexuals who reported at least one concurrent partnership was calculated from the Gallup data, data were stratified by gender and by cohort–age-class. Gender-specific frequency distributions are shown in table 3. It can be seen for both

Table 3. *Gender-specific age-stratified percentage of individuals who report different types of sexual partnerships*

(These data are from heterosexuals who report at least one lifetime sexual partner in the Gallup study (males, $n = 188$; females, $n = 309$).)

	% of males who report different types of sexual partnerships					
age class	16–24	25–34	35–44	45–54	55–64	totals
only one sex partner	38	40	41	54	69	40
males who report more than one lifetime sexual partner						
only serial monogamous partnerships	26	28	31	23	28	28
at least one concurrent partnership	35	32	29	23	3	26
	% of females who report different types of sexual partnerships					
age class	16–24	25–34	35–44	45–54	55–64	totals
only one sex partner	50	44	55	84	90	61
females who report more than one lifetime sexual partner						
only serial monogamous partnerships	29	41	26	10	10	26
at least one concurrent partnership	21	15	19	6	0	13

sexes that younger individuals are more likely to have a concurrent partnership than older individuals.

Age–cohort effects and partnership duration

The Gallup partnership data were also used to derive gender-specific frequency distributions for the duration of sexual partnerships in heterosexuals; these distributions were stratified by gender and by age-class–cohort. The frequency distributions for males are presented in figure 7; the patterns are similar in females. It can be seen for both sexes that the duration of partnerships is positively associated with increasing age-class–cohort, younger people tend to have short relationships, although considerable variability is apparent.

(ii) *Short-term behaviour changes*

Many, if not all, sexual behaviours are extremely heterogeneous, therefore changes in sexual behaviour have to be analysed at both the population level and the subgroup level. Data were analysed to determine: the degree of risk perception, which (if any) subgroups changed their sexual behaviour, the type of behavioural changes that occurred, the magnitude of the behaviour changes (with relationship to the initial level of the risk behaviour) and the timing of the behaviour changes.

Population level behavioural changes

Frequency distributions of the number of reported sex partners over time in the four BMRB sampling waves were examined to explore population level changes in sexual behaviour. Distributions for heterosexuals and homosexuals for sampling waves 2, 3 and 4 are shown in figures 1 and 2 (sampling wave 1 is not shown as the wording of the question concerning the reported number of sex partners differed considerably between wave 1 and subsequent waves). No population level changes are readily apparent in the heterosexual distributions in figure 1, and only a slight

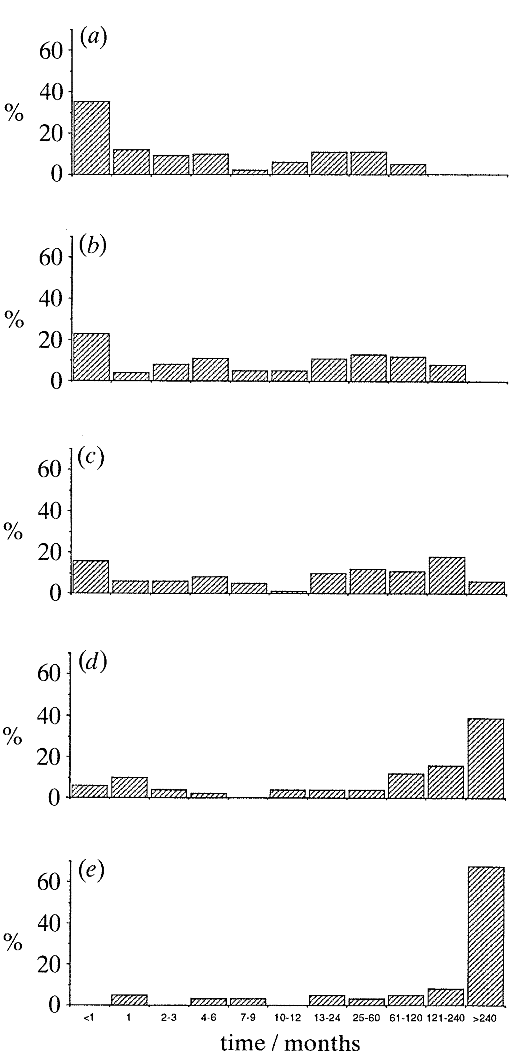

Figure 7. Frequency distributions for male heterosexuals of the duration of sexual partnerships, stratified on the basis of age-class (*a*: 16–24 year olds; *b*: 25–34 year olds; *c*: 35–44 year olds; *d*: 45–54 year olds; *e*: 55–64 year olds); calculated from the Gallup partnership data ($n = 448$). The y-axis is the proportion of sexual partnerships.

reduction in the proportion of homosexual males who report at least two partners in the previous year is seen in figure 2.

Subgroup level behavioural changes: risk perception

Whether an individual will change behaviour may depend upon both their level of risk behaviour and their perception of their risk. Only 11% of males and 13% of females (Harris data) perceived themselves to be at moderate or high risk, 54% of males and 48% of females perceived themselves to be at no risk. Log-linear modelling of the Harris data revealed that risk perception was associated ($p < 0.05$) with the reported number of sex partners in the previous 5 years; male and female heterosexuals who reported higher numbers of sex partners perceived themselves to be at greater risk than those who reported lower numbers of partners. Risk perception was also associated ($p < 0.05$) with age–cohort for males; younger males perceived themselves to be at greater risk than older males.

Subgroup level behavioural changes: potentially at-risk subgroups

Only a minority of heterosexuals reported changing their sexual behaviour; 17% of males and 17% of females (with at least one sex partner in the previous 5 years) reported that publicity about AIDS had caused them to change their sexual behaviour. Log-linear modelling revealed a significant association ($p < 0.001$) in both males and females between perceived risk and behaviour change; individuals who perceived themselves to be at greater risk reported more behaviour change than those who perceived themselves to be at lower risk. The log-linear models identified an association for both male and female heterosexuals (who reported at least one sex partner in the previous 5 years) between sexual behaviour changes and the reported number of sex partners in the previous 5 years (see figure 8); a greater proportion of individuals with higher number of partners reported behavioural changes than individuals with low numbers of partners. The models also identified an association ($p < 0.001$) in males for change in sex behaviour and age–cohort; a greater proportion of younger males reported behavioural change than older males.

Subgroup level behavioural changes: type of behavioural change

Many types of sexual behaviour changes can occur; the data were analysed to assess the behavioural changes in the reported number of sex partners per unit time and also changes in other specific sexual activities. Frequency distributions for the reported number of sex partners over time (BMRB 4 waves of data) for the most sexually active individuals were calculated. Sexually active individuals were defined as individuals who reported at least two female sex partners in the previous year (for heterosexual and bisexual men) or individuals who reported at least one male sex partner in the previous year (for homosexual men). The number of reported sex partners in the

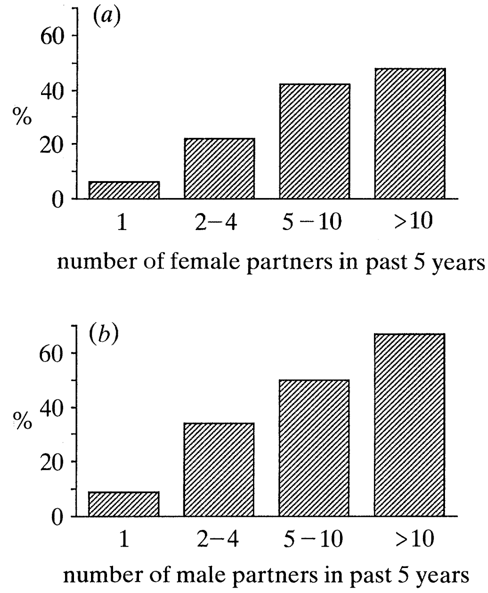

Figure 8. Gender-specific frequency distributions (*a*: males; *b*: females): the proportion of heterosexuals who reported recent sexual behaviour changes is plotted on the *y*-axis, the reported number of lifetime sex partners is plotted on the *x*-axis. These percentages were calculated from the Harris data for heterosexuals who reported at least one sex partner in the previous five years (males: $n=348$; females: $n=324$).

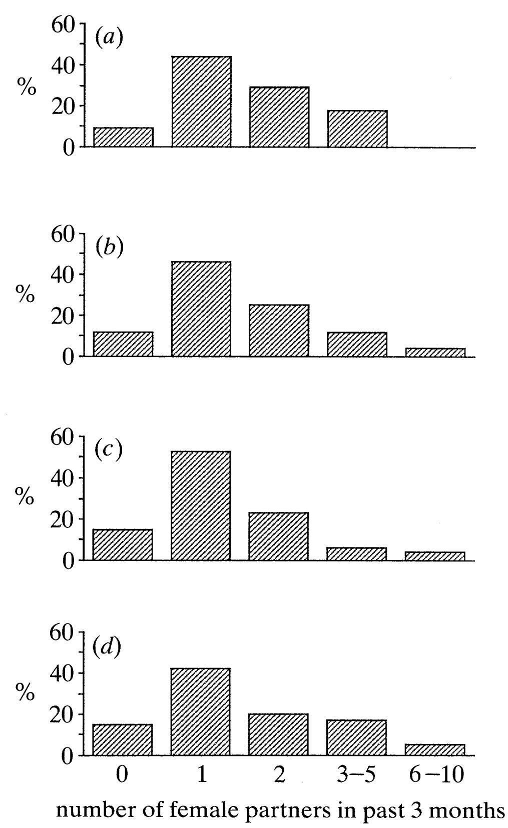

Figure 9. Frequency distributions: the proportions of male heterosexuals is plotted on the *y*-axis, reported number of opposite sex partners in the previous three months is plotted on the *x*-axis; calculated from the BMRB data (*a*: wave 1 ($n=66$); *b*: wave 2 ($n=97$); *c*: wave 3 ($n=53$); *d*: wave 4 ($n=59$)). All of these males had reported at least two female sex partners in the previous 12 months.

previous three months for heterosexual males, bisexual males, and homosexual males are shown in figures 9, 10 and 11 respectively. Similar frequency distributions were not generated for females, due to the low numbers of females who reported two or more sex partners. No dramatic sexual behavioural changes are readily apparent in figures 9, 10 or 11. As previously discussed, means and variances could not be calculated for any of these frequency distributions as the BMRB had only collected categorical data, an examination of the time trends in the summary statistics (e.g. the mean and variance) of these distributions would have been useful.

Other potential sexual behaviour changes in these sexually active subgroups were investigated by examining time trends in specific sexual behaviour changes that were reported in the four sampling waves of the BMRB study (see table 4). Time trends can be assessed from these data for sexually active male homosexuals, male heterosexuals and male bisexuals. Table 4 reveals the time trends in the proportion of individuals reporting specific types of sexual behaviour changes; for example, the proportion of heterosexual males reporting a decreased number of sex partners, increased use of condoms and decreased sex with strangers, increases with time. Hence, although a significant amount of sexual behaviour change (in

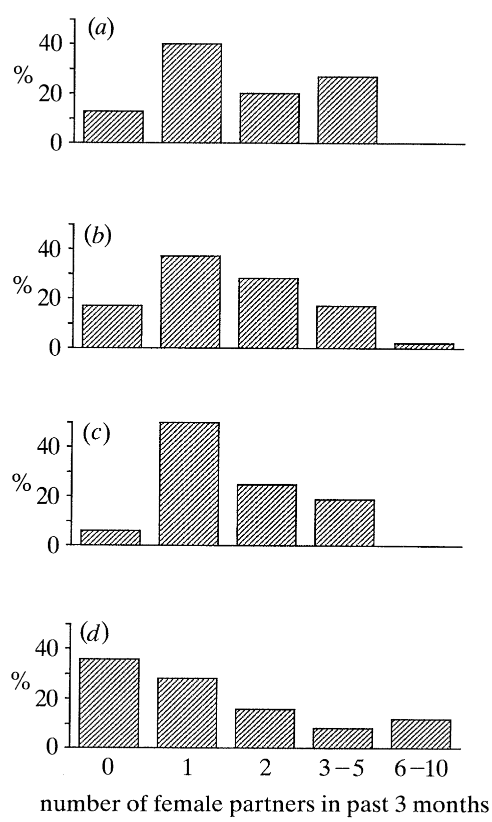

Figure 10. Frequency distribution: the proportion of male bisexuals is plotted on the y-axis, the reported number of opposite sex partners in the previous 3 months is plotted on the x-axis; calculated from the BMRB data (a: wave 1 ($n=15$); b: wave 2 ($n=54$); c: wave 3 ($n=16$); d: wave 4 ($n=25$)). All of these male homosexuals had reported at least two female sex partners in the previous 12 months.

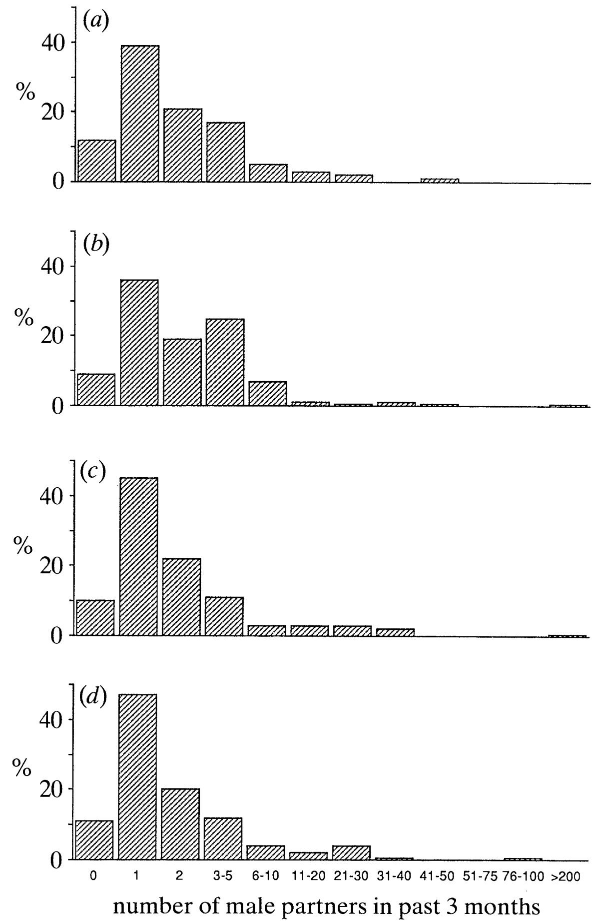

Figure 11. Frequency distributions: the proportion of male homosexuals is plotted on the y-axis, the reported number of same sex partners in the previous 3 months is plotted on the x-axis; calculated from the BMRB data (a: wave 1 ($n=131$); b: wave 2 ($n=247$); c: wave 3 ($n=233$); d: wave 4 ($n=190$)). All of these males had reported at least one male sex partner in the previous 12 months.

terms of the numbers of sex partners per unit time) may not be apparent from an examination of the frequency distributions, significant changes in other sexual risk behaviours may have occurred. Due to the low number of women who reported high numbers of sex partners per unit time, it was impossible to use the BMRB data to assess gender differences in behaviour change. However, the Harris data indicate there are significant differences in how male and female heterosexuals changed their sexual behaviour (see table 5); whilst the majority of males decreased their numbers of sex partners, a considerable proportion of females refused to have sex.

Subgroup level behavioural changes: magnitude & timing

The magnitude of the behaviour change that occurred varied considerably among the different subgroups; the data in table 4 (BMRB data) indicate that reported behaviour changes were considerably greater in homosexual and bisexual men than in heterosexual men. However, the degree of behaviour change that is possible (and necessary) in any subgroup depends upon the initial level of the risk

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

Table 4. *Percentage of males who report changes in specific sexual behaviours, the data are from the BMRB study*

(Sample sizes: heterosexuals (wave 1 = 72, wave 2 = 100, wave 3 = 59, wave 4 = 62); bisexuals (wave 1 = 20, wave 2 = 56, wave 3 = 29, wave 4 = 31); homosexuals (wave 1 = 144, wave 2 = 273, wave 3 = 264, wave 4 = 218).)

heterosexual males who report more than one female sex partner in the previous 12 months

	wave			
reported behaviour changes	1 (%)	2 (%)	3 (%)	4 (%)
decreased number of sex partners	24	28	27	39
increased use of condoms	12	11	22	32
decreased anal sex	10	10	9	11
decreased sex with strangers	25	21	32	34

bisexual males, homosexuals who report more than one female sex partner in the previous 12 months

	Wave			
reported behaviour changes	1 (%)	2 (%)	3 (%)	4 (%)
decreased number of sex partners	50	39	66	52
increased use of condoms	35	21	52	55
decreased anal sex	25	20	34	39
decreased sex with strangers	50	27	48	71

homosexual males who report at least one male sex partner in the previous 12 months

	wave			
reported behaviour changes	1 (%)	2 (%)	3 (%)	4 (%)
decreased number of sex partners	67	65	64	67
increased use of condoms	23	24	37	45
decreased anal sex	51	51	42	42
decreased sex with strangers	63	57	60	67

behaviour, the initial prevalence of many sexual behaviours was significantly higher in homosexual men than in heterosexual men and consequently more change was possible (and necessary). For example, see figure 12, this figure shows the time trends from the BMRB data in the prevalence of anal intercourse in male heterosexuals, bisexuals and homosexuals. As can be seen from the distributions, the initial prevalence of anal intercourse is low in both heterosexual and bisexual males and there is no apparent change in behaviour. The initial prevalence of anal intercourse is high in homosexual males, the prevalence changes dramatically over time, but the final prevalence is still higher than the prevalence in heterosexual men. The data (in table 4) also imply that significant behaviour change may have occurred in all three sexually active subgroups before the first BMRB sample was collected in February 1986.

Table 5. *Gender-specific sexual behaviour changes reported by heterosexuals in the Harris study*

(Only 17% of heterosexuals (52 males and 41 females) reported sexual behaviour changes.)

	males (%)	females (%)
behavioural changes		
refuse sex	2	22
decrease number of sex partners	60	24
insist on condoms	19	24
learn safer sex	14	15
other	6	15

(*e*) *Calculation of epidemiological parameters*

Preliminary assessment of the potential for a heterosexually driven epidemic can be made by using the data to estimate two epidemiological parameters, the basic reproductive rate and the initial doubling time of the epidemic. These parameters were calculated from the Gallup and the Harris data. The value of R_o is very sensitive to the values of the transmission efficiencies of the virus and the duration of infectiousness, any increases in these parameters will increase R_o (see equation 1); as discussed in the methodology section, minimum estimates of parameter values were used. The value of R_o calculated from the data is also model dependent, other models may produce different estimates. Although the calculated values of R_o should be interpreted with caution, the value of R_o does serve as a useful indicator variable.

The three estimated values of R_o from the Gallup data were 0.8 (calculating the rate of change of sex partners from 5 years to 1 year), 0.7 (calculating the rate of change of sex partners from 5 years to 2 years) and 1.6 (calculating the rate of change of sex partners from 2 years to 1 year). The estimated value of R_o

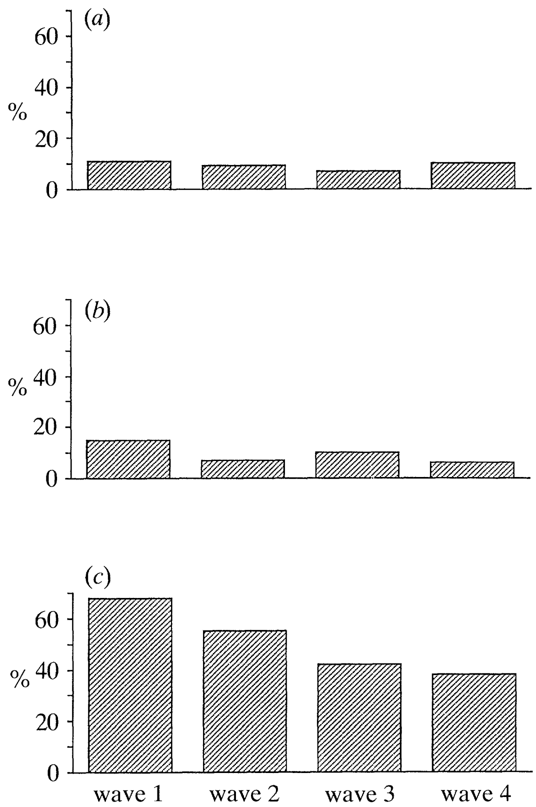

Figure 12. Frequency distributions: the proportion of males who reported practising anal intercourse (with females (*a*, *b*) or with males (*c*)) in the previous 12 months is plotted on the *y*-axis; calculated from the BMRB data. (*a*) shows the proportions for male heterosexuals who had reported at least two female sex partners in the previous 12 months; sample sizes (at each wave) were 72, 100, 59 and 62. (*b*) shows the proportions for male bisexuals who had reported at least two female sex partners in the previous 12 months; sample sizes (at each wave) were 20, 56, 29 and 31. (*c*) shows the proportions for male homosexuals who had reported at least one male sex partner in the previous 12 months; sample sizes (at each wave) were 144, 273, 264 and 218.

from the Harris data was 0.7 (calculating the rate of change of sex partners from 5 years to 1 year). Age-stratified R_os were also calculated for the different age-classes in the Gallup and the Harris samples, these R_os are shown in table 6. As can be seen in both sexes and in both surveys, the net reproductive rate is greatest in the youngest age groups. These findings may explain why the three estimates of R_o derived from the Gallup data differ; they may differ because the R_os are implicitly weighted by age. Because younger people are the most sexually active and they are just initiating their sexual activity, their average yearly rates of sex partner change will be higher over the more recent time intervals. Consequently, the highest value of R_o (1.6) was obtained using the data from the most recent time period, when the rates of sex partner change were calculated by using the values for the reported number of sex partners 2 years and 1 year ago. The initial doubling time for the epidemic ranges from 2 years (using the maximum estimated value of R_o) to 14 years (assuming that the actual value of R_o is just greater than one).

4. DISCUSSION

(*a*) *Methodological problems*

There are many methodological problems associated with studying sexual behaviour, as reviewed by Blumstein *et al.* (1991). The validity (representativeness) of the measurements used remain unknown. Generally the degree of bias in an estimate can be assessed by collecting corroborating data from independent sources, in the case of sexual behaviour data, this tactic is clearly not possible. Response rates can be used to suggest the degree of selective participation that may have occurred; however, selective participation can only be assessed on the basis of certain demographic characteristics which may be unrelated to the sexual behavioural variables that are under study (Blumstein *et al.* 1990). The response rate of the Gallup data has been analysed and discussed elsewhere (Blower *et al.* 1990); other potential sampling biases in the Gallup data have been discussed by Johnson *et al.* (1989). In this study I have assessed data validity by comparing the demographic statistics for each of the three surveys with those of the general population. The demographic characteristics of all three survey samples were similar to census demographic statistics; however, this does not ensure that the estimates of the risk behaviours are unbiased. Consequently, as selective participation, on the basis of sexual behaviour, cannot be excluded, the results of this study must be interpreted with caution. Furthermore, the reliability (reproducibility) of the measurements is unknown. Many techniques have been used to assess the reliability of sexual behaviour data; for example, repeating interviews, the use of polygraphs, comparing interviews with sexual diaries, interviewing sexual partners, urine testing (for sperm) and using randomized response methodology (Blumstein *et al.* 1990; Coates *et al.* 1988). Results from studies of the reliability of sexual behavioural data indicate that such data are fairly reliable; for example, Padian (1990*b*) compared the reported sexual histories within heterosexual couples by conducting separate interviews and found strong within couple agreement. As individuals tend to under-report rather than over report their sexual behaviours; consequently most estimates will be lower bound estimates (Blumstein *et al.* 1990). Each of the data sets that I have analyzed in this paper are imperfect, I have sought to assess the reliability of these data by comparing the results from the three studies. The qualitative patterns for specific variables, the frequency distributions of particular risk behaviours and the summary statistics for these distributions reveal similar patterns and estimates, suggesting that they are reliable. However, I wish to stress that due to the significant heterogeneity in sexual behaviour and the small sample sizes of the surveys, the results from this analysis should be interpreted with caution.

(*b*) *Prevalence and distribution of risk behaviours*

The results indicate that only a small proportion of heterosexuals report high numbers of sex partners or

Table 6. *These tables show the estimated age-stratified net reproductive rates (R_0s) calculated from the Gallup and Harris data*

(The annual rate of change of sex partners was estimated by calculating the difference in the number of reported partners in the previous 5 years and the previous 12 months, and then dividing by four. The summary statistics (mean and variance (var)) of the gender-specific frequency distributions of the annual rate of change of sex partners are shown in the tables. C is the 'effective average' rate of change of sex partners, and is estimated by adding the mean of the annual rate of change of sex partner to the variance to mean ratio. Sample sizes: Gallup males = 290; Gallup females = 380; Harris males = 141; Harris females = 94).

	Gallup (annual rate of change of sex partners)						
	males			females			
age	mean	var	C	mean	var	C	R_o
16–24	1.11	11.96	11.88	0.22	0.18	1.04	1.0
25–34	0.43	0.76	2.20	0.15	0.16	1.22	0.4
35–44	0.33	1.70	5.48	0.05	0.02	0.45	0.4
45–54	0.08	0.03	0.46	0.02	0.01	0.27	0.1
55–64	0.06	0.12	2.06	0.03	0.01	0.36	0.2
totals	0.44	3.26	7.85	0.10	0.09	1.00	0.8

	Harris (annual rate of change of sex partners)						
	males			females			
age	mean	var	C	mean	var	C	R_o
18–24	1.25	4.07	4.51	0.70	0.69	1.69	0.8
25–34	1.41	8.67	7.56	0.56	0.26	1.02	0.8
35–44	1.01	1.80	2.79	0.27	0.17	0.90	0.4
totals	1.25	5.03	5.27	0.54	0.41	1.30	0.7

practise anal intercourse. Oral intercourse in heterosexuals is fairly common, but it is still uncertain whether oral intercourse is a significant risk factor in heterosexual transmission. The results suggest that homosexuals tend to be more sexually active than heterosexuals both in terms of the number of sex partners per unit time, and in their practice of anal intercourse, suggesting that it is unlikely that a HIV-1 heterosexually transmitted epidemic in the U.K. could reach the current proportions of the homosexually transmitted epidemics in Europe and North America. The homosexual data that were analysed in this article were not randomly collected and therefore may not accurately reflect patterns of sexual behaviour in the general homosexual community. Homosexuals were recruited in exclusively homosexual pubs and clubs and thus the sample may be biased towards more sexually active men. However, many other studies of sexual behaviour of homosexual men have revealed that high risk sexual behaviours are fairly common (Doll *et al.* 1990; Ekstrand & Coates 1990; Evans *et al.* 1988; Fay *et al.* 1989; Ginzburg *et al.* 1988; Hays *et al.* 1990; Penkower *et al.* 1991; Schecter *et al.* 1988; van Griensven *et al.* 1988; 1989; Winkelstein *et al.* 1987; 1988).

(*c*) *Characterization of potentially at-risk subgroups*

The potentially at-risk heterosexual subgroups were characterized. The most sexually active individuals tended to be single, young and to occur in any socio-economic class. These individuals were the most likely to have short-term and concurrent sexual partnerships. These results have significant epidemiological implications, the presence of a high degree of concurrent partnerships among the most sexually active individuals could significantly increase the speed of an HIV-1 epidemic. These findings indicate that it is most important to monitor sexual behaviour in the younger age-groups.

(*d*) *Age-dependent sexual mixing patterns*

An individual's risk of acquiring the virus is dependent not only upon their number of sex partners per unit time and the specific sexual activities that they engage in, but is also affected by whom they choose as their sex partner (i.e. the sexual mixing pattern). Mixing patterns among individuals can be specified on the basis of a variety of characteristics. The epidemiological effects of different types of sexual mixing patterns have been investigated by formulating mathematical models of the transmission dynamics of HIV-1 (Blower 1990, 1991; Blower *et al.* 1991; Gupta & Anderson 1990; Hyman & Stanley 1989; Koopman *et al.* 1988). Age-dependent mixing patterns in heterosexually transmitted epidemics have been modelled and the results suggest that age-dependent mixing patterns can be extremely important in determining the magnitude of the epidemic (Anderson *et al.* 1990; Gupta & Anderson 1990; Knolle 1990). Unfortunately, it is extremely difficult to collect the appropriate data in order to accurately measure actual mixing patterns; furthermore mixing patterns may not be constant and can change significantly with time (Blower & McLean 1991). In this article, I identified an age-dependent mixing pattern for heterosexuals (based upon the Gallup data). This mixing pattern revealed that there may be considerable mixing among age classes; older men are having sexual intercourse with younger women, but significant variability in the degree of sexual mixing within age classes is also apparent. This mixing pattern suggests that if HIV-1 establishes and spreads within the younger more sexually active age groups, younger women could then transmit the virus to older men, and heterosexual transmission could be fairly extensive. The age-dependent mixing pattern is not the only important mixing pattern. Recently, the number of European and North American heterosexually transmitted AIDS cases has begun to increase substantially in areas that contain large numbers of IDU. It appears that IDU may be acting as an infection source and that the epidemic may be slowly diffusing out into the general population; hence, it is essential to determine the heterosexual behaviour of IDU (Anneke *et al.* 1990; Donoghoe *et al.* 1989). To assess the potential for a heterosexually transmitted HIV-1 epidemic it is critical to understand: the transmission dynamics of HIV-1 within the IDU communities, the degree of sexual mixing among IDU and non-injecting heterosexuals, and current and future (needle or syringe-sharing and sexual) behaviour changes that occur in the IDU communities. Recent behaviour change studies in IDU indicate that IDU may be more likely to change their injecting behaviour than their sexual behaviour (Robert *et al.* 1990; Sasse *et al.* 1989). These findings suggest that HIV-1 may continue to diffuse out into the general population from the IDU communities by heterosexual transmission. Furthermore, the analysis of a mathematical model of the transmission dynamics of HIV-1 among IDU and heterosexuals in New York City suggests that the degree of sexual mixing that occurs among the IDU communities and the rest of the heterosexual population is an essential component for determining the future number of AIDS cases that are attributable to heterosexual transmission (Blower 1990).

(*e*) *Sexual behaviour changes*

The results suggest that the population level change in the reported numbers of sex partners per unit time were insignificant. However, significant changes in specific sexual activities were reported in the most sexually active subgroups, and there were significant gender differences in changes in sexual behaviour. The magnitude of the behaviour change varied considerably among the different subgroups. Reported behaviour changes were considerably greater in homosexual and bisexual men than in heterosexual men. However, the initial (and the final) levels of the risk behaviour remained highest in homosexual men. The data also imply that significant behaviour change may have occurred in the sexually active subgroups before February 1986. These results are in agreement with findings by Evans *et al.* (1989) who evaluated trends in sexual behaviour in homosexual men in the U.K. between 1984 and 1987. These authors found a decrease in casual relationships and other high risk activities, with the greatest behavioural changes occurring before 1986. Data from San Francisco also indicate that significant changes in sexual risk behaviours in homosexual men had occurred by 1984 (Doll *et al.* 1990; Winkelstein *et al.* 1988).

The results suggest that few heterosexuals perceived themselves to be at risk of acquiring HIV-1, younger males and individuals who reported high numbers of sex partners perceived themselves to be at the greatest risk. Individual risk perception may be fairly accurate, as only a small proportion of heterosexuals report high numbers of sexual partners. The results imply that individuals who perceived themselves to be at the greatest risk were more likely to report behaviour changes than other individuals. Other studies have also shown that risk perception is critical for sexual behaviour change, and that behaviour change is more apparent among young single individuals (Allard 1989). The results in this study suggest that if individual risk perception was accurate, behaviour changes may have already occurred among the minority of individuals that were the most critical in the transmission dynamics of HIV-1. However, even if risk behaviour changes occurred, these changes may not have been of epidemiological significance (Blower 1991). For example, a mathematical modelling study of HIV-1 transmission among IDU and non-injecting heterosexuals demonstrates that certain behaviour changes do not reduce the future number of AIDS cases (Blower 1991; Blower *et al.* 1991). To evaluate the epidemiological significance of risk behaviour changes it is necessary to know: the type, the magnitude and the timing of the behavioural change, as well as the seroprevalence level (at which the behaviour change occurs) and the (sexual and needle or syringe-sharing) mixing patterns. Furthermore, even if extensive sexual behaviour changes occur, they have to be maintained. A recent study of homosexual and bisexual men has shown that 12% exhibited relapses in their sexual behaviour changes over a four year period (Ekstrand & Coates 1990). Hence, even with reported behaviour changes it remains possible that a heterosexually transmitted HIV-1 epidemic could occur in the U.K.

It is also important to note that when population level risk behaviour changes are observed, it should not simply be concluded that they are the result of behavioural intervention strategies. Significant changes in population level risk behaviour can occur due to differential mortality effects (i.e. the more sexually active individuals are selectively removed from the population) (Anderson & May 1988*a*; Blower & van Griensven 1992) and also due to the supply and demand dynamics of sexual partnerships (Le Pont & Blower 1991). Sexual behavour can be thought of in terms of supply and demand dynamics (Le Pont & Blower 1991); within this conceptual framework an individual is both the resource and the consumer. Consequently, when an individual changes his or her sexual behaviour the changes have simultaneous effects on the demand side (e.g. there is now one fewer individual who is looking for a sexual partner) and on the supply side (e.g. there is now one fewer individual who is available to become a sexual partner). Therefore any change in behaviour by an individual has to affect the sexual behaviour of the rest of the population (whether or not the rest of the population 'wanted' to change their sexual behaviour). Behavioural rules must exist that determine how individuals behave in the face of changes in the availability of sex partners (Anderson & May 1988*a*; Anderson *et al.* 1989; Le Pont & Blower 1991). These behavioural rules can be conceptualized as implicit sexual behaviour change (ISBC) mechanisms because these behaviour changes occur independently of any intervention strategy, and are simply due to the changes in the availability of partners (Le Pont & Blower 1991). The ISBC mechanisms specify how males and females modify their rates of sex partner change in response to changes in the availability of the opposite sex that arise due to recruitment and mortality during the epidemic. The epidemiological importance of ISBC mechanisms in the heterosexual transmission of HIV-1 has been investigated by mathematical modelling (Le Pont & Blower 1991). This modelling endeavour has shown dramatic changes in population level sexual behaviour can occur, without any individual behavioural change occurring.

(*f*) *Epidemiological parameters*

The epidemiological parameters estimated from both the Gallup and the Harris studies should be interpreted with caution, the calculated values of R_o are only approximate and the values may be inaccurate if the models assumptions are violated. Also, rates of partner change had to be estimated from the data, as data were only collected on the number of partners per unit time, and not rates of change. This adjustment of the data could lead to additional errors in the estimation of R_o. The results indicate that R_o, in the general population, may be slightly greater or slightly smaller than 1. The results also suggest that R_o can vary significantly among different age groups and that R_o may be considerably greater than one in the younger age groups due to their higher than average rates of sex partner change. Therefore, whether or not a heterosexually transmitted HIV epidemic will occur in the U.K. will depend upon the precise value of R_o in the younger age groups, the size of these sexually active groups and the degree to which these groups sexually interact with the rest of the population. It should also be noted that the formula for estimating the reproductive rate is based upon a simple model that does not take into account age-dependent mixing patterns and concurrent partnerships. Recently, more complicated formulations of R_o have been devised (Knolle 1990). If these complexities are included in the calculation of R_o, it seems likely that the reproductive rate of the virus in the younger age groups would be considerably greater than one and there would be the potential for a heterosexually transmitted HIV-1 epidemic to occur in the U.K. The current slow increase in incidence of reported AIDS cases in the U.K. (due to heterosexual transmission) may reflect a long doubling time. However, it is important to note that even with a long doubling time, if R_o is greater than 1, then HIV-1 will continue to spread slowly among the general population. Such a slow rate of spread will be difficult to detect in the absence of data from either very large scale seroprevalence surveys of the general population, or much smaller surveys of the potential at-risk subgroups.

In summary, an analysis of the available data suggests that it remains possible that a heterosexually transmitted HIV-1 epidemic could occur in the U.K. Hence, it is essential to conduct longitudinal surveys that collect linked seroprevalence and risk behavioural data. Studies that link behavioural and seroprevalence data have been effectively employed to study cohorts of homosexual men and IDU (Ginzburgh *et al.* 1988; Penkower *et al.* 1991; Schechter *et al.* 1988; van den Hoek *et al.* 1990; van Griensven *et al.* 1988; 1989; Winkelstein *et al.* 1987, 1988). To monitor heterosexual transmission, it would be most effective to follow cohorts of at-risk individuals, rather than the entire population; cohorts of young single individuals who report high numbers of sex partners per unit time could be recruited. Linked longitudinal studies guarantee that an individual's risk behaviour change data can be linked to their serostatus and their initial level of risk behaviour; hence such studies would ensure that the spread of the epidemic could be adequately monitored and that the epidemiological effects of special risk behaviour change could be evaluated. Finally, to determine the potential for a heterosexually transmitted HIV-1 epidemic in the U.K. it is also critical to measure and to monitor the sexual mixing patterns.

I acknowledge the financial support of the Medical Research Council and the HIV Center for Clinical and Behavioural Studies at Columbia University & New York State Psychiatric Institute, New York (grant number 5-P50-MH43520). I also thank Roy Anderson, Nelson Freimer, Bob May and Jim Wiley for their comments on earlier versions of this manuscript.

REFERENCES

Allain, J.P. 1986 Prevalence of HTLV-III/LAV antibodies in patients with haemophilia and their sexual partners in France. *N. Engl. J. Med.* **315**, 517–518.

Allard, R. 1989 Beliefs about AIDS as determinants of preventive practices and of support for coercive measures. *Am. J. publ. Hlth* **79**(4), 448–452.

Anderson, R.M., Blythe, S.P., Gupta, S. & Konings, E. 1989 The transmission dynamics of the human immunodeficiency virus type 1 in the male homosexual community in the United Kingdom: the influence of changes in sexual behaviour. *Phil. Trans. R. Soc. Lond.* B **325**, 49–98.

Anderson, R.M., Gupta, S. & Ng, W. 1990 The significance of sexual partner contact networks for the transmission dynamics of HIV. *JAIDS* **3**, 417–429.

Anderson, R.M. & May, R.M. 1988*a* The transmission dynamics of HIV. *Phil. Trans. R. Soc. Lond.* B **321**, 565–607.

Anderson, R.M. & May, R.M. 1988*b* Epidemiological parameters of HIV transmission. *Nature, Lond.* **333**, 514–519.

Anderson, R.M., Medley, G.F., May, R.M. & Johnson, A.M. 1986 A preliminary study of the transmission dynamics of the human immunodeficiency virus (HIV), the causative agent of AIDS. *IMAJ. Math. Appl. Med. Biol.* **3**, 229–263.

Blower, S.M. 1991 Behaviour changes & stabilization of seroprevalence levels, correlation or causation? *JAIDS* **4**, 920–923.

Blower, S.M. 1990 HIV epidemiology and sexual mixing patterns in intravenous drug using communities. *6th International Conference on AIDS, San Francisco, U.S.A.*, June 1990. (Abstract 678.)

Blower, S.M., Anderson, R.M. & Wallace, P. 1990 Loglinear models, sexual behaviour and HIV: epidemiological implications of heterosexual transmission. *JAIDS* **3**, 763—772.

Blower, S.M., Hartel, D., Dowlatabadi, H., May, R.M. & Anderson, R.M. 1991 Drugs, sex and HIV: a mathematical model for New York City. *Phil. Trans. R. Soc. Lond.* B **321**, 171–187.

Blower, S.M. & McLean, A.R. 1991 Mixing ecology & epidemiology. *Proc. R. Soc. Lond.* B **245**, 187–192.

Blower, S.M. & van Griensven, G.J.P. 1992 Differential mortality and risk behaviour change: implications for HIV seroconversion rates. (Submitted.)

Blumstein, P.W., Dawes, R.M., Lindenbaum, S. & Rudkin-Miniot, L. 1990 Methodological Issues in AIDS surveys. In *AIDS: the second decade* (H. G. Miller, C. F. Turner & L. E. Moses), pp. 359–472, Washington, DC: National Academy Press.

BMRB 1989 *AIDS advertising campaign: report for surveys during the first year of advertising*. London: British Market Research Board.

Cameron, D.W., Simonsen, J.N., D'Costa, L.J. & Ronald, A.R. 1989 Female and male transmission of HIV-1: risk factors for seroconversion in men. *Lancet i*, 403–407.

Coates, R.A., Calzara, L.M., Soskolne, C.L. & Read, S.E. 1988 Validity of sexual histories in a prospective study of male sexual contacts of men with AIDS or an AIDS related condition. *Am. J. Epidemiol.* **128**(4), 719–728.

Doll, L.S., O'Malley, P.M., Pershing, A.L. & Darrow, W.W. 1990 High-risk sexual behaviour & knowledge of HIV antibody status in the San Francisco City Clinic Cohort. *Hlth Psychol.* **9**(3), 253–265.

Donoghoe, M.C., Stimson, G.V. & Dolan, K.A. 1989 Sexual behaviours of injecting drug users and associated risks of HIV infection for non-injecting sexual partners. *AIDS CARE* **1**(1), 51–58.

Ekstrand, M.L. & Coates, T.J. 1990 Maintenance of safer sexual behaviors and predictors of risky sex: The San Francisco Men's Health Study. *Am. J. publ. Hlth* **80**(8), 973–977.

European Study Group 1989 Risk factors for male to female transmission of HIV. *Br. med. J.* **298**, 411–415.

Evans, B.A., McLean, K.A., Dawson, S.G. & Teece, S.A. 1989 Trends in sexual behaviour and risk factors for HIV infection among homosexual men, 1984–7. *Br. med. J.* **298**, 215–8.

Fay, R.E., Turner, C.F., Klassen, A.D. & Gagnon, J.H. 1989 Prevalence and patterns of same-gender sexual contact among men. *Science, Wash.* **243**, 338–348.

Fischl, M.A., Dickson, D.M. & Scott G.B. 1987 Evaluation of heterosexual partners, children and household contacts of adults with AIDS. *J. Am. med. Ass.* **257**, 640–644.

France, A.J., Skidmore, C.A., Robertson, R.P. & Roberts, J.J.K. 1988 Heterosexual spread of HIV in Edinburgh. *Br. med. J.* 526–529.

Ginzburg, H.M., Fleming, P.L. & Miller, K.D. 1988 Selected public health observations derived from the multicenter AIDS cohort study. *JAIDS* **1**, 2–8.

Gupta, S. & Anderson, R.M. 1990 Age-dependent sexual behaviour amongst male homosexuals and the transmission dynamics of HIV-1. *Scand. J. Infect. Dis. Suppl.* **69**, 187–197.

Haverkos, H.W. & Edelman, R. 1988 The epidemiology of acquired immunodeficiency syndrome among heterosexuals. *J. Am. med. Ass.* **260**(13), 1922–1929.

Holmes, K.K., Karon, J.M. & Kreiss, J. 1990 The increasing frequency of heterosexually acquired AIDS in the United States, 1983–88. *Am. J. publ. Hlth* **80**(7), 858–863.

Hyman, J.M. & Stanley, E.A. 1989 The effects of social mixing patterns on the spread of AIDS. In Mathematical approaches to ecological & environmental problem solving. *Lect. Notes Biomath.* **81**, 190–219.

Johnson, A.M. & Laga, M. 1988 Heterosexual transmission of HIV. *AIDS* **2**(suppl 1), S49–S56.

Johnson, A.M., Wadsworth, J. & Elliot, P. 1989 A pilot study of sexual lifestyle in a random sample of the population of Great Britain. *AIDS* **3**, 135–141.

Jones, P., Hamilton, P.J. & Bird, G. 1985 AIDS and haemophilia: morbidity and mortality in a well defined population. *Br. med. J.* **291**, 695–699.

Kahn, H.A. & Sempos, C.T. 1989 *Statistical methods in epidemiology. Monographs in epidemiology & biostatistics*, vol. 12. Oxford University Press.

Knolle, H. 1990 Age preference in sexual choice and the basic reproductive number of HIV/AIDS. *Biom. J.* **2**, 243–256.

Koopman, J., Simon, C., Jacquez, J., Joseph, J., Sattenspiel, L. & Park, T. 1988 Sexual partner selectiveness effects on homosexual HIV transmission dynamics. *JAIDS* **1**, 486–504.

Le Pont, F. & Blower, S.M. 1991 The supply & demand dynamics of sexual behaviour: implications for heterosexual HIV epidemics. *JAIDS* **4**, 987–999.

Macdonald, G. 1952 The analysis of equilibrium in malaria. *Trop. Dis. Bull.* **49**, 813–829.

Marmor, M., Krasinski, K., Sanchez, M. & Cohen, H. 1990 Sex, drugs, and HIV infection in a New York City Hospital Outpatient population. *JAIDS* **3**, 307–318.

May, R.M. & Anderson, R.M. 1987 Transmission dynamics of HIV infection. *Nature, Lond.* **326**, 137–142.

May, R.M., Anderson, R.M. & Blower, S.M. 1989 The epidemiology and transmission dynamics of HIV/AIDS. *Daedalus* **118**(2), 163–201.

Padian, N., Marquis, L. & Francis, D. 1988 Male-to-female transmission of human immunodeficiency virus. *J. Am. med. Ass.* **258**, 788–790.

Padian, N. 1990*a* Heterosexual transmission: infectivity and risks. In *Heterosexual transmission of AIDS*, pp. 25–34. A. R. Liss.

Padian, N. 1990*b* Sexual histories of heterosexual couples with one HIV-infected partner. *Am. J. publ. Hlth* **80**(8), 990–991.

Penkower, L., Dew, M.A., Kingsley, L. & Becker, J.T. 1991 Behavioral, health and psychosocial factors and risk for HIV infection among sexually active homosexual men: The Multicenter AIDS Cohort Study. *Am. J. publ. Hlth* **81**(2), 194–196.

Piot, P., Plummer, F.A., Mhalu, F.S. & Lamboray, J.L. 1988 AIDS: an international perspective. *Science, Wash.* **239**, 573–579.

Quinn, T.C., Mann, J.M., Curran, J.W. & Pilot, P. 1986 AIDS in Africa: an epidemiologic paradigm. *Science, Wash.* **234**, 955–963.

Redfield, R.R., Markham, P.D. & Salahuddin, S.Z. 1985 Frequent transmission of HTLV-III among spouses of patients with AIDS-related complex and AIDS. *J. Am. med. Ass.* **253**, 1571–1573.

Robert, C.F., Deglon, J.J. & Wintsch, J. 1990 Behavioural changes in intravenous drug users in Geneva: rise and fall of HIV infection, 1990–1989. *AIDS* **4**, 657–660.

Rozenbaum, W., Gharakhanian, W., Cardon, B., Duval, E. & Coulaud, J.P. 1988 HIV transmission by oral sex. *Lancet i*, 1395.

Sasse, H., Salmasa, S. & Conti, S. 1989 First Drug User Multicenter Study Group. Risk behaviours for HIV-1 infection in Italian drug users: report from a multicenter study. *JAIDS* **2**, 486–496.

Schecter, M.T., Craib, K.J.P., Math, B.W. & Douglas, B. 1988 Patterns of sexual behaviour and condom use in a cohort of homosexual men. *Am. J. publ. Hlth* **78**(12), 1535–1538.

van den Hoek, J.A.R., van Haastrecht, H.J.A. & Coutinho, R.A. 1990 Heterosexual behaviour of intravenous drug users in Amsterdam: implications for the AIDS epidemic. *AIDS* **4**, 449–453.

van Griensven, G.J.P., de Vroome, E.M.M., Tielman, R.A.P. & Goudsmit, J. 1988 Impact of HIV antibody testing on changes in sexual behaviour among homosexual men in the Netherlands. *Am. J. publ. Hlth* **78**(12), 1575–1577.

van Griensven, G.J.P., de Vroome, E.M.M., Tielman, R.A.P. & Goudsmit, J. 1989 Effect of HIV antibody knowledge on high-risk sexual behaviour with steady and non-steady sexual partners among homosexual men. *Am. J. Epidemiol.* **129**(3), 596–603.

Winkelstein, W., Lyman, D.M. & Padian, N. 1987 Sexual practices and risk of infection by the human immunodeficiency virus. *J. Am. med. Ass.* **257**, 321–325.

Winkelstein, W., Wiley, J.A., Padian, N.S., Samuel, M., Shiboski, S., Ascher, M.S. & Levy, J.A. 1988 The San Francisco Men's Health Study: continued decline in HIV seroconversion rates among homosexual/bisexual men. *Am. J. publ. Hlth* **78**(11), 1472–1474.

Received 13 December 1991; revised 15 May 1992; accepted 25 June 1992