Parasitology

cambridge.org/par

Research Article

Cite this article: Tamari N, Minakawa N, Sonye GO, Awuor B, Kongere JO, Munga S, Larson PS (2019). Antimalarial bednet protection of children disappears when shared by three or more people in a high transmission setting of western Kenya. *Parasitology* **146**, 363–371. https://doi.org/10.1017/S003118201800149X

Received: 30 March 2018
Revised: 29 July 2018
Accepted: 13 August 2018
First published online: 10 September 2018

Key words:
Bed nets; bednet sharing; children; Kenya; long-lasting insecticide treated nets; malaria; *Plasmodium*; universal coverage

Author for correspondence:
Noriko Tamari, E-mail: norikotamari@gmail.com

Antimalarial bednet protection of children disappears when shared by three or more people in a high transmission setting of western Kenya

Noriko Tamari[1,2], Noboru Minakawa[2], George O. Sonye[3], Beatrice Awuor[3], James O. Kongere[4], Stephen Munga[5] and Peter S. Larson[6,7]

[1]Graduate School of Tropical Medicine and Global Health, Nagasaki University, 1-12-4 Sakamoto, Nagasaki, Nagasaki, 852-8523, Japan; [2]Institute of Tropical Medicine, Nagasaki University, 1-12-4 Sakamoto, Nagasaki, Nagasaki, 852-8523, Japan; [3]Ability to Solve by Knowledge Project, Mbita, Homa Bay, Kenya; [4]Centre for Research in Tropical Medicine and Community Development, Nairobi, Kenya; [5]Centre for Global Health Research, Kenya Medical Research Institute, Kisumu, Kenya; [6]NUITM-KEMRI Project, Institute of Tropical Medicine, Nagasaki University, Nairobi, Kenya and [7]Department of Epidemiology, School of Public Health, University of Michigan, Ann Arbor, Michigan, USA

Abstract

A sizeable proportion of households is forced to share single long-lasting insecticide treated net (LLIN). However, the relationship between increasing numbers of people sharing a net and the risk for *Plasmodium* infection is unclear. This study revealed whether risk for *Plasmodium falciparum* infection is associated with the number of people sharing a LLIN in a holoendemic area of Kenya. Children ⩽5 years of age were tested for *P. falciparum* infection using polymerase chain reaction. Of 558 children surveyed, 293 (52.5%) tested positive for parasitaemia. Four hundred and fifty-eight (82.1%) reported sleeping under a LLIN. Of those, the number of people sharing a net with the sampled child ranged from 1 to 5 (median = 2). Children using a net alone or with one other person were at lower risk than non-users (OR = 0.29, 95% CI 0.10–0.82 and OR = 0.47, 95% CI 0.22–0.97, respectively). On the other hand, there was no significant difference between non-users and children sharing a net with two (OR = 0.88, 95% CI 0.44–1.77) or more other persons (OR = 0.75, 95% CI 0.32–1.72). LLINs are effective in protecting against *Plasmodium* infection in children when used alone or with one other person compared with not using them. Public health professionals should inform caretakers of the risks of too many people sharing a net.

Introduction

Long-lasting insecticide treated nets (LLINs or nets thereafter) have been shown to reduce malaria morbidity and mortality in endemic areas (Lengeler, 2004; Eisele *et al.*, 2010) and are now accepted as an important tool in programmes to control *Plasmodium* transmission (World Health Organization, 2016). Initially, pregnant women and children <5 of age were targeted to receive LLINs (World Health Organization, 2014). Since 2007, the World Health Organization (WHO) has recommended that programmes provide one LLIN for every two people sleeping in a single structure. This recommendation is part of guidelines for achieving 'universal coverage' to prevent malaria, assuming that even those in low-risk groups contribute to community-wide transmission (Fegan *et al.*, 2007; World Health Organization, 2007).

Despite the WHO recommendation of two people per net and intense mass distribution campaigns which have increased overall net possession (World Health Organization, 2016), a sizeable proportion of households have only one net and thus are forced to share them (Ngondi *et al.*, 2011; Zhou *et al.*, 2014). Shortfalls in LLIN coverage result from several factors including problems of insufficient LLIN procurement (Kilian *et al.*, 2010). Even when LLINs are sufficient to cover all family members, circumstances may require a member to share a net with two or more persons. As children age, they sleep on the floor or move to a smaller structure (Alaii *et al.*, 2003; Baume *et al.*, 2009; Noor *et al.*, 2009; Galvin *et al.*, 2011). Thus, the mean number of people per net often exceeds the recommended number (Larson *et al.*, 2014; Zhou *et al.*, 2014; Msellemu *et al.*, 2017). Risk of infection may increase because of limited space. Children may touch the sides, extremities might extend outside and children may roll outside, particularly when sleeping on the floor. In fact, a past study reported that children sleeping on the floor were more likely to be parasitemic (Minakawa *et al.*, 2015).

Though groups regularly follow the WHO guideline of 'one net for every two people' to achieve universal coverage, the recommendation lacks empirical support. Specifically, it is unclear whether increasing numbers of people sharing a net impact risk for *Plasmodium* infection and, if so, to what extent. Few studies have been done to show (1) if two people per net is optimal to prevent infection and (2) if there exists a maximum number of people that might share a net, and still preserve the protective effect of the LLIN in a holoendemic context. This research aims to answer these questions regarding risk for *Plasmodium falciparum* infection among children in an area of high endemicity along Lake Victoria in Kenya.

Materials and methods

Study area and target population

The study area was in the Gembe East Sub-location in Homa Bay County, Kenya (12 km^2; 0°28′24.06″S, 34°19′16.82″E) (Fig. 1). Principal economic activities include fishing and farming (Iwashita *et al.*, 2010; Larson *et al.*, 2014; Minakawa *et al.*, 2015). A typical household compound consists of families living in multiple mud house structures often with corrugated iron roofs that have open eaves (Iwashita *et al.*, 2010; Minakawa *et al.*, 2015).

Plasmodium infection data among children in this area were available from an ongoing field evaluation study for the development of a rapid diagnostic test (RDT) (Yatsushiro *et al.*, 2016). The area was divided into 12 community sub-areas (Fig. 1). Most LLINs in the area were distributed in September to October of 2014. For the RDT study, a census of the area was performed. In August 2016, there were 3,792 people living in the study area. All children ⩽5 were considered for inclusion, of which there were 727 at the time of the census.

The present study was designed as cross-sectional survey, and we conducted the field survey twice performed in September 2016 and April 2017. In August 2016, survey workers visited each household known to have at least one eligible child. During visits, staff informed household heads about the survey, and the locations and dates of blood sample collection, which was to be done at local schools and community areas. Workers explained the goals, risks and benefits of the study and obtained written consent. If no one was present, survey workers returned to the household daily until an adult was found. In September 2016, the parasitaemia survey was performed. A follow-up survey was performed between October and December 2016, when survey workers collected information on LLIN use and other relevant data. The parasitaemia and follow-up surveys were repeated in March 2017.

Measurement of P. falciparum *infection*

During both screening rounds, axillary temperature was measured and a finger prick blood sample was taken for all children. Initial testing for parasitaemia was performed in the field using an RDT (Paracheck® Pf-Rapid Test for *P. falciparum*, ver.3, Orchid Biomedical Systems, Verna, Goa, India). Artemether–lumefantrine was given to children following a diagnosis by a clinician under WHO guidelines (World Health Organization, 2015). Blood samples were examined to detect *P. falciparum* using polymerase chain reaction (PCR).

Background information

Caretakers were asked to report whether the child slept under a bed net the previous night, in a manner consistent with other surveys (Baume *et al.*, 2009; Noor *et al.*, 2009; Iwashita *et al.*, 2010; Eisele *et al.*, 2011; Minakawa *et al.*, 2015). A follow-up survey was administered at the household to obtain contextual information on LLIN usage, sleeping location and household construction. Caretakers were asked to report the number of people sleeping under the same net with the sampled child the previous night as well as the age, gender and sleeping location of the child. Anything used for sleeping other than a framed bed was considered 'non-bed', defined as sleeping on the floor, on a sofa or on a mattress without a bed frame. Staff also obtained information on the numbers of household members and rooms. Workers directly observed the number of LLINs in each household. Geographical coordinates of house structures were recorded using a handheld global positioning system (GPS) (Garmin, Olathe, KS, USA). Distance to the nearest water body was calculated using GPS coordinates of the house and polygon shapefiles for water bodies.

Socioeconomic status (SES) for each household was measured using a composite household material wealth index based on possession of various consumer goods, household construction, toilet/water access and livestock (Filmer and Pritchett, 2001; Traissac and Martin-Prevel, 2012). These data were collected through a health demographic surveillance system from February to April 2017 (Wanyua *et al.*, 2013). Presence or absence of each item was recorded, and a numerical score was assigned to each using multiple correspondence analysis. The continuous measure was then divided into tertiles to obtain a rough proxy of socioeconomic 'classes' (Traissac and Martin-Prevel, 2012).

In January 2017, indoor resting female mosquitoes were also collected in rooms where children slept, using the pyrethrum spray catch method (Silver and Springerlink, 2008). Room area was measured used a tape measure. Mosquitoes were grouped by genus under a dissecting microscope. Among anopheline species, *Anopheles arabiensis* and *An. funestus* are most common in this area (Iwashita *et al.*, 2010; Minakawa *et al.*, 2012; Futami *et al.*, 2014).

Data were collected on paper forms. Data entry was performed by two people and independently verified. When discrepancies or missing data were found, staff were sent back to households to confirm or recollect data.

Statistical methods/data analysis

Data collected included age, mosquito density, gender, net availability, number of rooms, SES, sleeping location and month of sample collection (September or March). Mosquito density was calculated as the number of mosquitoes divided by the area of sleeping room. Both anopheline and culicine mosquitoes were considered in the analysis of LLIN use because people do not distinguish between mosquito genera when using nets. Only anophelines were considered in models of parasitaemia. Net availability was calculated as the number of bed nets divided by the number of household members. Longitude and latitude were included to consider spatial variability in infection.

Descriptive statistics were produced for all relevant variables in the dataset. Logistic regression was used to test associations of LLIN use (yes/no) by the child with potentially predictive variables. Next, the dataset was restricted to only those children who slept under a LLIN. Using this subset, associations were tested between the variables and the number of people the sampled child shared the net with using multinomial logistic regression.

Logistic regression was used to test infection risk and the number of people (ordinal) sharing a LLIN and other variables. To determine whether the relationship between the number of people sharing the net and the other variables held, a multivariate logistic regression model was created using a backward selection procedure using Akaike's Information Criterion (AIC). While every effort was made to insure data completeness in the field, missing data in the variables other than parasitaemia and the number of people sharing the net were imputed using a multiple imputation method. Checks were made to ensure that the imputation process did not compromise the integrity of the results. The study design presented the potential for clustering at several levels. Since some of children were tested in both September 2016 and March 2017, individuals were considered as a potential random effect along with household and sub-area. All data were analysed using R (version 3.4.3) (Team, 2006).

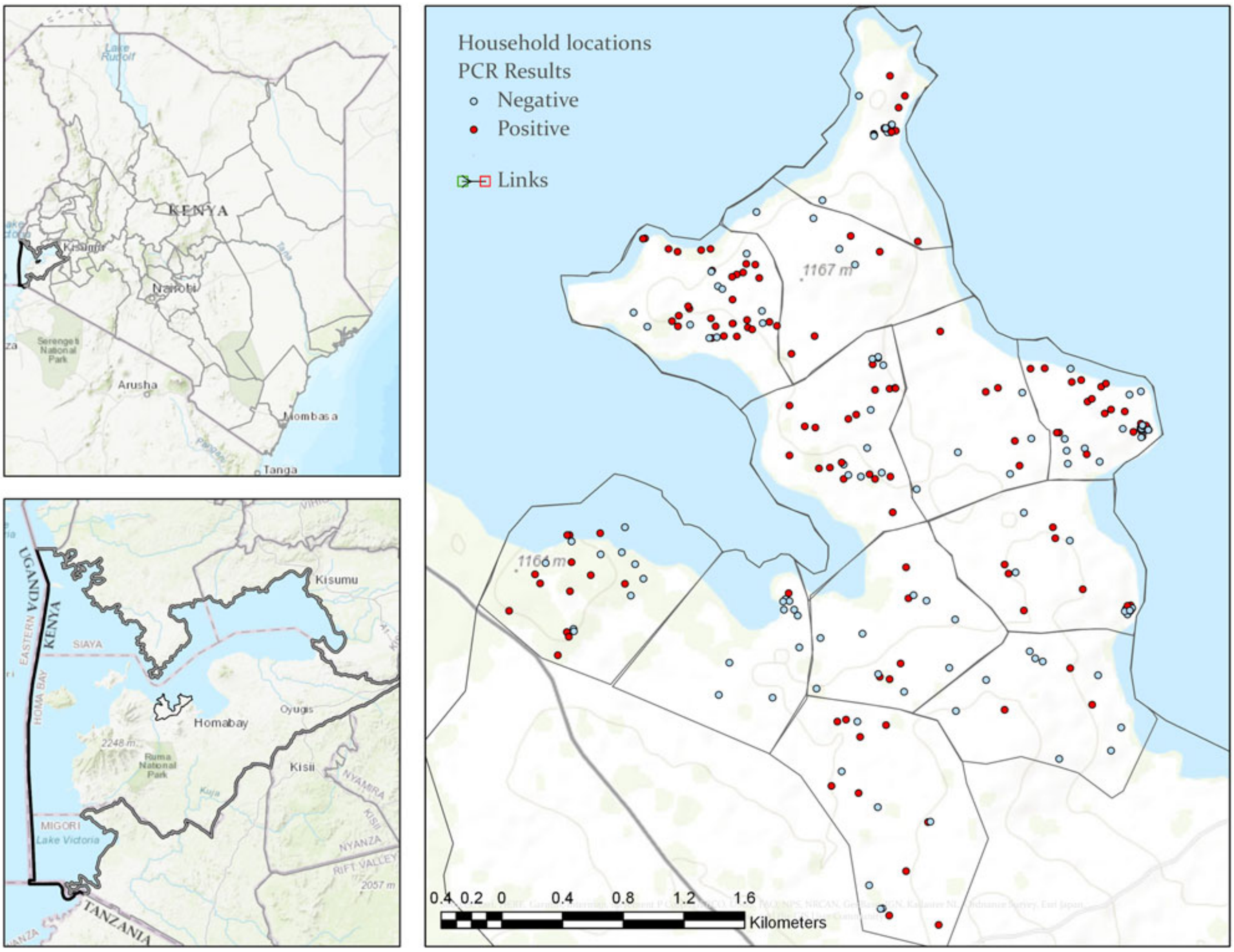

Fig. 1. Location of study area, surveyed households and spatial distribution of *Plasmodium* infection status by PCR.

Results

Target population

In September 2016, 623 children were tested for *P. falciparum* parasite infection, and the data from 268 children were used in the analyses. Of the 355 children excluded, 291 children slept in the houses that had ceilings screened with a LLIN material, which was thought to compromise analysis of relationships of LLIN use and malaria risk (Kawada *et al*., 2012). Sixty-four children were excluded because they were >5 years of age, moved during follow-up or lived outside the study area. In March 2017, 557 children were tested and the data from 290 children were used. Of the 267 children excluded, 241 children slept in homes that had a ceiling-net, 26 children were >5 or from outside the study area. In total, 558 children from 250 households were included in the analyses (Fig. 2).

Power calculation

According to previous study in this region, the prevalence of malaria infection among children <5 who slept under a net was 62.8%, while that of children who did not was 74.3% (Minakawa *et al*., 2015). Assuming a type I error rate of 5% and a sample size of 558, the power to detect a difference in parasitaemia among net users and non-users was 0.99.

LLIN use and possession

Of 558 children, 458 (82.1%) reported sleeping under a LLIN the night before the survey. LLINs were present in the households of 78 of the 100 (78%) children who were reported to not have used a LLIN (Table 1). Of 458 children who slept under a net, 33 (7.2%) slept alone. The remaining children (92.8%) shared a net with at least one person (median: 2, range: 1–5, $n = 425$). The median number of nets per household was 2 (range: 0–10), and the median number of people per household was 5 (range: 2–15). The mean number of persons per net was 3.12 (S.E. = 0.10) among the 237 households that had at least one net.

The number of children sharing a net with four or more persons was only 15 and one, respectively. These children were grouped with those sharing with three other persons. Excluding non-net users from the dataset, the multinomial regression analyses revealed several variables that were significantly associated with the number of people sharing a net with the sampled child (Table 2). Children sharing a net with two other persons had the lowest mean age, and the mean was significantly lower than those of children sleeping alone and children sharing a net with one other person. Male children shared a net with fewer persons, and children who slept in a bed shared a net with more people (see Table 2 for full results).

Plasmodium falciparum *infection and LLIN use*

Among 558 children, 293 (52.5%) tested positive for parasitaemia by PCR. The PCR-positive prevalence of net users and non-users was 49.3 and 67.0%, respectively (Table 1), and the odds of testing positive was significantly lower for net users compared with non-users (OR = 0.48, 95% CI 0.30–0.75).

For the regression analyses of parasitaemia and LLIN use, we explored several models. First, given that GPS locations of

https://doi.org/10.1017/S003118201800149X Published online by Cambridge University Press

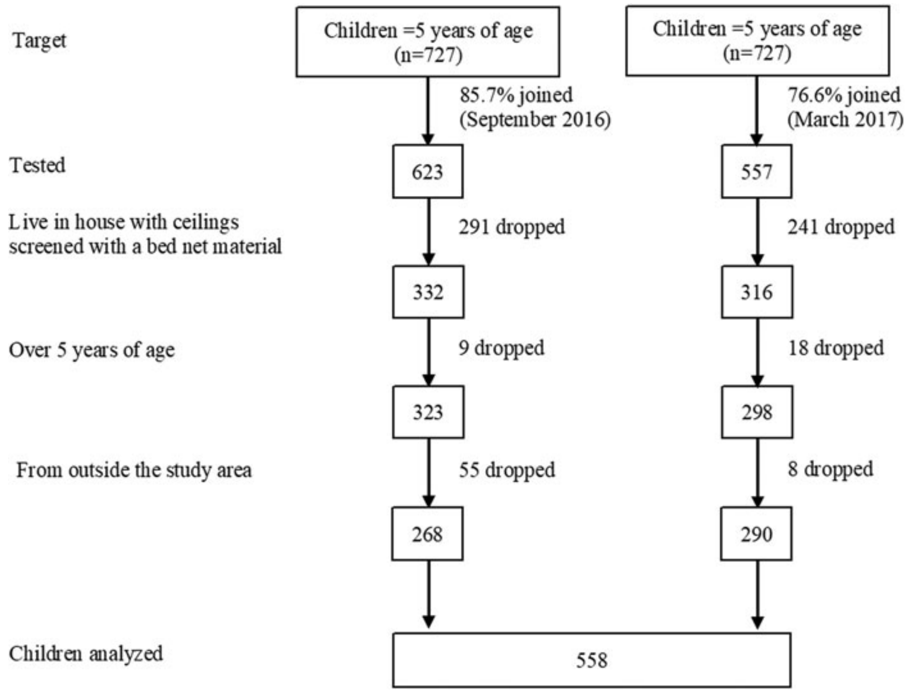

Fig. 2. Flowchart of parasitaemia sampling and inclusion in the final sample. Note: the field survey was performed twice in September 2016 and April 2017 for the same target.

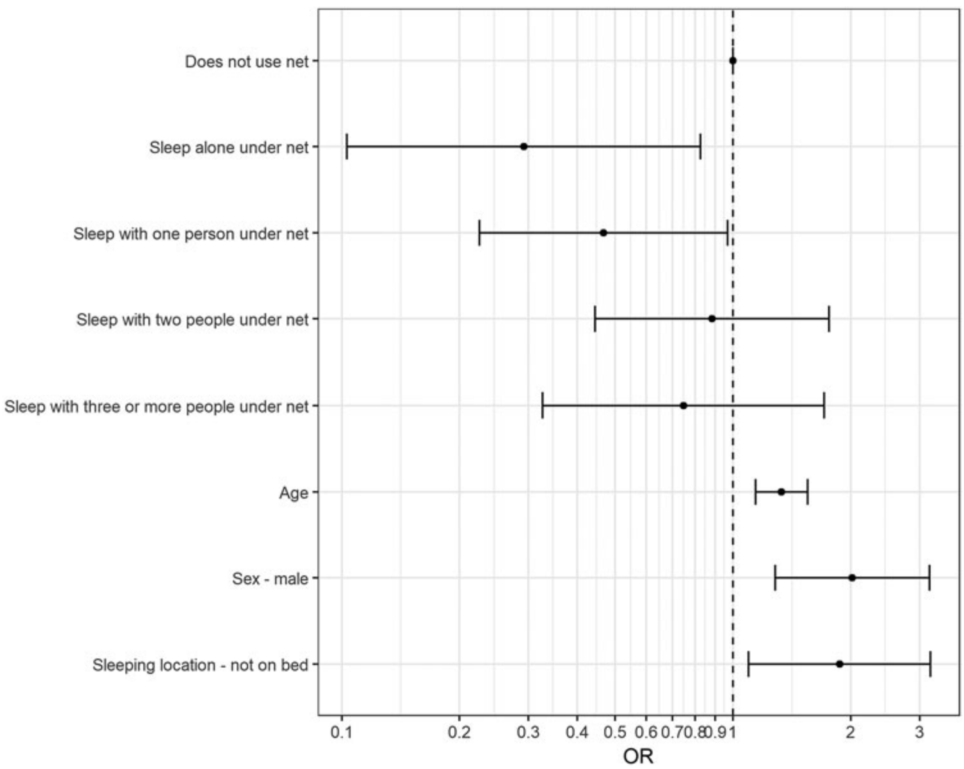

Fig. 3. Odds ratios and confidence intervals for parasitaemia given the number of people sharing a LLIN and confounding variables. Parameters were estimated after model selection.

households were known (Fig. 1), we tested for spatial autocorrelation of parasitaemia status through Moran's *I*. We also examined caterpillar plots of random intercepts for sub-area, household and individuals, under the assumption that parasitaemia status of individuals would be influence by that parasitaemia status of the surrounding environment, community and household members. We found that there was evidence for spatial autocorrelation in the dataset (Moran's *I*: 0.17, $P < 0.0001$) for cases in the study area. When exploring different options to account for spatial autocorrelation, it was found that spatial clustering disappeared when including a random effect for household (Moran's *I*: −0.13, $P = 1$). Attempts at modelling spatial autocorrelation were unsuccessful. So we settled on using mixed models for the bivariate and multivariate models including a random effect for household.

Bivariate logistic regression analyses including a random effect for household revealed that the risk increased as the number of people sharing a net increased although the odds of testing

Table 1. Profiles of bed net users and non-users

Variable	Number of people sharing LLIN among those who used LLINs				All net users	Non-users	Everyone
	Alone	With one person	With two people	With three or more			
Age[a]	4 (1–5)	4 (0–5)	2 (0–5)	4 (0–5)	3 (0–5)	4 (0–5)	3 (0–5)
Gender[b]							
Female	13 (39.4)	63 (50.8)	119 (52.9)	49 (64.5)	244 (53.3)	48 (48.0)	292 (52.3)
Male	20 (60.6)	61 (49.2)	106 (47.1)	27 (35.5)	214 (46.7)	52 (52.0)	266 (47.7)
PCR[b]							
Negative	19 (57.6)	66 (53.2)	112 (49.8)	35 (46.1)	232 (50.7)	33 (33.0)	265 (47.5)
Positive	14 (42.4)	58 (46.8)	113 (50.2)	41 (53.9)	226 (49.3)	67 (67.0)	293 (52.5)
Bed net availability[c]	0.56 ± 0.19	0.48 ± 0.18	0.37 ± 0.12	0.33 ± 0.13	0.4 ± 0.16	0.16 ± 0.12	0.36 ± 0.18
Size of room (m^2)[c,d]	11.75 ± 4.25	10.91 ± 4.21	9.87 ± 4.13	10.64 ± 4.79	10.43 ± 4.3	11.68 ± 5.21	10.61 ± 4.46
Number of rooms[a]	2 (1–5)	2 (1–5)	2 (1–6)	2 (1–4)	2 (1–6)	2 (1–6)	2 (1–6)
Sleeping location[b]							
Bed	6 (18.2)	41 (33.1)	137 (60.9)	30 (39.5)	214 (46.7)	19 (19.0)	233 (41.8)
Non-bed	27 (81.8)	83 (66.9)	88 (39.1)	46 (60.5)	244 (53.3)	81 (81.0)	325 (58.2)
Socioeconomic status[b]							
Low	7 (21.2)	38 (30.9)	77 (34.2)	19 (25.3)	141 (30.9)	45 (45.0)	186 (33.5)
Middle	8 (24.2)	46 (37.4)	77 (34.2)	16 (21.3)	147 (32.2)	39 (39.0)	186 (33.5)
High	18 (54.6)	39 (31.7)	71 (31.6)	40 (53.3)	168 (36.9)	16 (16.0)	184 (33.0)
Density of anophelines (m^{-2})[a,d]	0.19 (0–21.26)	0.61 (0–22.11)	0.84 (0–21.26)	0.42 (0–10.94)	0.62 (0–22.11)	1.73 (0–56.31)	0.65 (0–56.31)
Density of mosquitoes (m^{-2})[a,d]	0.19 (0–21.39)	0.61 (0–22.11)	0.91 (0–21.39)	0.42 (0–11.29)	0.64 (0–22.11)	1.73 (0–56.67)	0.65 (0–56.67)
Distance to water (km)[c,e]	0.31 ± 0.29	0.35 ± 0.26	0.29 ± 0.29	0.21 ± 0.29	0.36 ± 0.36	0.36 ± 0.36	0.29 ± 0.28
Month of sample collection[b]							
September 2016	13 (39.4)	68 (54.8)	107 (47.6)	39 (51.3)	227 (49.6)	41 (41.0)	268 (48.0)
March 2017	20 (60.6)	56 (45.2)	118 (52.4)	37 (48.7)	231 (50.4)	59 (59.0)	290 (52.0)

[a]Median (range).
[b]%.
[c]Mean ± standard error.
[d]N = 376.
[e]N = 555.

Table 2. Association of each explanatory variable with bed net use and the number of people sharing a bed net with a child

	LLIN use[a]			Number of people sharing LLIN among those who used LLINs[b]			
Variable	No *N* = 100	Yes *N* = 458	OR (95% CI)	Alone	With one person OR (95% CI)	With two people OR (95% CI)	With three or more people OR (95% CI)
Age[c]	3.63 ± 1.35	2.82 ± 1.78	0.74 (0.64–0.85)[d]	*Ref.*	0.93 (0.72–1.2)	0.63 (0.49–0.8)[d]	0.83 (0.64–1.08)
Gender[e]							
Female	48 (48.0)	244 (53.3)	*Ref.*	*Ref.*	*Ref.*	*Ref.*	*Ref.*
Male	52 (52.0)	214 (46.7)	0.81 (0.52–1.25)	*Ref.*	0.63 (0.29–1.38)	0.58 (0.27–1.22)	0.36 (0.15–0.83)[d]
Bed net availability[c]	0.16 ± 0.12	0.40 ± 0.16	5.88×10^6 (2.72×10^5–1.27×10^8)[d]	*Ref.*	0.16 (0.02–1.08)	0 (0–0)	0 (0–0)
Area of room (m^2)[c]	11.7 ± 5.21	10.4 ± 4.30	0.94 (0.89–1.00)	*Ref.*	0.96 (0.87–1.06)	0.91 (0.82–1.0)	0.95 (0.85–1.05)
Number of rooms[c]	2.14 ± 1.07	2.15 ± 0.97	1.01 (0.79–1.30)	*Ref.*	1.29 (0.84–1.96)	1.07 (0.71–1.6)	0.98 (0.62–1.54)
Sleeping location[e]							
Bed	19 (19.0)	214 (46.7)	*Ref.*	*Ref.*	*Ref.*	*Ref.*	*Ref.*
Non-bed	81 (81.0)	244 (53.3)	0.27 (0.15–0.45)[d]	*Ref.*	0.45 (0.17–1.18)	0.14 (0.06–0.36)[d]	0.34 (0.13–0.92)[d]
Socioeconomic status[e]							
Low	45 (45.0)	141 (30.9)	*Ref.*	*Ref.*	*Ref.*	*Ref.*	*Ref.*
Middle	39 (39.0)	147 (32.2)	1.20 (0.74–1.96)	*Ref.*	1.06 (0.35–3.19)	0.88 (0.3–2.53)	0.74 (0.22–2.48)
High	16 (16.0)	168 (36.8)	3.32 (1.83–6.32)[d]	*Ref.*	0.4 (0.15–1.06)	0.36 (0.14–0.91)[d]	0.82 (0.29–2.29)
Density of mosquitoes (m^{-2})[c]	9.00 ± 17.2	1.71 ± 3.20	0.90 (0.85–0.95)[d]	*Ref.*	0.99 (0.86–1.15)	1.02 (0.89–1.17)	0.96 (0.81–1.14)
Distance to water (km)	0.36 ± 0.36	0.30 ± 0.29	0.52 (0.27–1.02)	*Ref.*	1.59 (0.43–5.88)	0.81 (0.23–2.87)	0.21 (0.04–1.01)
Month of sample collection[e]							
September 2016	41 (41.0)	227 (49.6)	*Ref.*	*Ref.*	*Ref.*	*Ref.*	*Ref.*
March 2017	59 (59.0)	231 (50.4)	0.71 (0.45–1.10)	*Ref.*	0.54 (0.24–1.17)	0.72 (0.34–1.51)	0.62 (0.27–1.42)

[a]Results are based on binary logistic regression analysis.
[b]Results are multinomial logistic regression analysis.
[c]Mean ± standard error.
[d]Statistically significant.
[e]%.

Table 3. Results from bivariate logistic regression analyses that measured the impact of the number of persons sharing a net and other explanatory variables on PCR-positive prevalence ($N = 558$)

Variable	Negative $N = 265$	Positive $N = 293$	OR (95% CI)
Number of people sharing LLIN[a]			
Non-user	33 (33.0)	67 (67.0)	*Ref.*
Sleeping alone	19 (57.6)	14 (42.4)	0.36 (0.13–0.95)[b]
Sharing with one person	66 (53.2)	58 (46.8)	0.42 (0.21–0.84)[b]
Sharing with two people	112 (49.8)	113 (50.2)	0.44 (0.23–0.80)[b]
Sharing with three or more people	35 (46.1)	41 (53.9)	0.58 (0.26–1.27)
Age[c]	2.55 ± 1.81	3.34 ± 1.57	1.30 (1.17–1.45)[b]
Gender[a]			
Female	156 (53.4)	136 (46.6)	*Ref.*
Male	109 (41.0)	157 (59.0)	1.92 (1.26–3.02)[b]
Bed net availability[c]	0.38 ± 0.18	0.35 ± 0.17	0.39 (0.11–1.36)
Area of room (m^2)[c]	11.0 ± 4.70	10.3 ± 4.22	0.97 (0.91–1.00)
Number of rooms[c]	2.09 ± 1.01	2.21 ± 0.95	1.10 (0.85–1.40)
Sleeping location[a]			
Bed	138 (59.2)	95 (40.8)	*Ref.*
Non-bed	127 (39.1)	198 (60.9)	2.77 (1.80–4.43)[b]
Socioeconomic status[a]			
Low	70 (37.6)	116 (62.4)	*Ref.*
Middle	84 (45.2)	102 (54.8)	0.66 (0.36–1.18)
High	109 (59.2)	75 (40.8)	0.31 (0.16–0.55)[b]
Density of anophelines (m^{-2})[c]	1.62 ± 4.86	3.68 ± 9.21	1.10 (1.01–1.10)[b]
Month of sample collection[a]			
September 2016	126 (47.0)	142 (53.0)	*Ref.*
March 2017	139 (47.9)	151 (52.1)	0.99 (0.67–1.50)
Distance to water (km)[c]	0.31 ± 0.32	0.31 ± 0.29	1.00 (0.47–2.20)

A random effect for household was included in the bivariate analyses.
[a]%.
[b]Statistically significant.
[c]Mean ± standard error.

positive was not significantly different for children sharing a net with three and more other persons than not sleeping under a LLIN at all. Other factors that were associated with parasitaemia included age, gender, sleeping location, density of anophelines, high SES and house location (see Table 3).

The multivariate logistic regression model of parasitaemia created using model selection included covariates for the number of people sharing a net with the sampled child and three other factors: age, gender and sleeping on a bed *vs* not (Table 4). Increasing age, male sex and not sleeping on a bed were associated with increased infection risk. For the number of people sharing a LLIN, risk for parasitaemia was only lower than sleeping without a net for those who slept under a net alone or shared it with one other person. The odds of testing positive for parasitaemia for those sharing the net with two or more persons was not different than not sleeping under a LLIN (Fig. 3).

Discussion

PCR-positive prevalence among children ⩽5 years of age was positively associated with the number of people sharing a net. Most troubling, the risk of parasitaemia in children who slept under a net with two or more people was not significantly different from the risk of not sleeping under a net at all. Although several field studies have confirmed the benefit of bed nets in reducing *Plasmodium* infection (Lindblade *et al*., 2004; Noor *et al*., 2008; Atieli *et al*., 2011; Minakawa *et al*., 2015), the present study showed that the protective effect of LLINs might be compromised when too many people share them.

Even in the presence of other factors known to increase risk for parasitaemia such as sleeping on the floor (Minakawa *et al*., 2015), age, gender and spatial location, the protective effect of LLINs was cancelled for those children who shared a net with more than two people. This indicates that the compromised effectiveness of LLINs for increased numbers of people sharing them might not be simply a factor of housing conditions, poverty or environmental risk. While further studies should be conducted to uncover the exact reasons for this result, we speculate that this could be due to crowded conditions where limbs sometimes extend outside the nets allowing opportunities for anophelines to bite. It is also possible that with more people sleeping under the nets, more people enter and exit the LLIN during the night, allowing opportunities for anophelines to enter, thus providing extra opportunities to bite and transmit.

These results suggest that the effectiveness is maximized when a child uses a net alone but still protected when sharing the net

https://doi.org/10.1017/S003118201800149X Published online by Cambridge University Press

Table 4. Results from multiple logistic regression analysis that compared the impact of the number of persons sharing a bed net on PCR-positive prevalence with non-bed net users

Variable	Adjusted OR (95% CI)
Number of people sharing LLIN	
Non-user	*Ref.*
Sleeping alone	0.29 (0.10–0.82)[a]
Sharing with one person	0.47 (0.22–0.97)[a]
Sharing with two people	0.88 (0.44–1.77)
Sharing with three or more people	0.75 (0.32–1.72)
Age	1.33 (1.15–1.56)[a]
Gender	
Female	*Ref.*
Male	2.02 (1.29–3.23)[a]
Sleeping location	
Bed	*Ref.*
Non-bed	1.87 (1.10–3.25)[a]

Parameters were estimated after model selection.
A random effect for household was included in the model, to account for within-household clustering of cases. Missing values in some variables were imputed using a multiple imputation method to allow for the creation of a multiple regression model using all subjects at hand (N = 588).
[a]Statistically significant.

with one other person so that malaria control programmes which centre on LLINs will be most effective if the WHO recommendation of 'one net for every two people' is followed (World Health Organization, 2007; Allen *et al.*, 2017). Of course, this recommendation will not be practical if both parents sleep with an infant or if sleeping spaces in the household are constrained. Placing the child between parents' bodies may be the solution for reducing the risk for the child, or a larger net may be recommended for families who wish to sleep under the same net (Kawada *et al.*, 2012). Regardless, groups distributing LLINs should take care to make people aware of the increased risks of too many people sharing a net.

If a household possesses few nets, more people will be required to share them. In our study area, even when considering the case of parents sleeping with infants, the ratio of people to nets (3.12 person per net) was far more than the recommendation despite proactive distribution efforts through the local health ministry to ensure universal coverage. While spatial constraints and practical factors will limit the ability of households to allow everyone to sleep under a net, public health groups might consider a smaller target when planning mass distributions of LLINs. For example, public health planners might use a target of 1.8 persons per net as has been proposed in another study, to account for spatial limitation and heterogeneous numbers of family members in households (Kilian *et al.*, 2010). Gender differences and variability in home sizes might suggest that an even smaller target be considered, such as 1.6 persons per net. More work needs to be done to determine an optimal target considering contextual differences in lifestyles and endemicity.

There were several limitations to this study. First, the limited area of the study and the close proximity to the lake might have compromised the generalizability of our results to other contexts, particularly households that are located in inland or highland locations. Second, the parasitaemia status of other people sharing the net with the children in this study was unknown. Third, though we are confident in the validity of our results in this particular context, a larger sample size might have elucidated more precise results of numbers of people sharing nets and parasitaemia risk. Future studies should look at this topic over a number of different transmission contexts and should look at effects of the parasitaemia status of the people sharing nets from all age groups.

This research demonstrated that the risk of *P. falciparum* infection among children increases with an increase in the number of people sharing a net with them and that the protective effect of a LLIN disappears when more than two people sleep with a child. This evidence suggests that the WHO recommendation of 'one net for every two people' is adequate, and that public health groups who plan distributions should take exceptional care to follow it to maximize protection. Public health professionals should also take care to advice recipients of LLINs on the risks of too many people sharing LLINs. However, further studies should be done to account for other factors to optimize this number for holoendemic areas.

Acknowledgements. We thank all the children participated, their parents, local communities and schools for understanding our study; Prof Mark L. Wilson and Dr Toshihiko Sunahara for their critical comments; Ms Junko Sakemoto, Prof Yoshio Ichinose, Ms Yukie Saito, Ms Shizuko Yagi for administrative support; Ms Naomi Sano for PCR analysis; Mr Peter A. Lutiali for mosquito identification; Mr Charles O. Gunga, Ms Lucy Oketch, Mr Fredrick O. Sonye and all the local staff members for their dedication of the fieldwork; Mr Morris Ndemwa of the NUITM – KEMRI Health Demographic Surveillance System for his help in obtaining household and contextual data. This study was conducted at the Kenya Research Center, Institute of Tropical Medicine, Nagasaki University, Japan. This paper is published with the permission of the Director of Kenya Medical Research Institute.

Financial support. This study was partially supported by Global Health Innovative Technology Fund and conducted at the Joint Usage/Research Center for Tropical Disease, Institute of Tropical Medicine, Nagasaki University, Japan.

Conflict of interest. None.

Ethical standards. This study was approved by the Ethics Committees of the Kenya Medical Research Institute (SSC No.3168) and the Ethics Review Committee of Graduate School of Tropical Medicine and Global Health, Nagasaki University (No.12).

References

Alaii JA, Van Den Borne HW, Kachur SP, Shelley K, Mwenesi H, Vulule JM, Hawley WA, Nahlen BL and Phillips-Howard PA (2003) Community reactions to the introduction of permethrin-treated bed nets for malaria control during a randomized controlled trial in western Kenya. *American Journal of Tropical Medicine and Hygiene* **68**, 128–136.
Allen EP, Muhwezi WW, Henriksson DK and Mbonye AK (2017) Health facility management and access: a qualitative analysis of challenges to seeking healthcare for children under five in Uganda. *Health Policy and Planning* **32**, 934.
Atieli H, Zhou G, Afrane Y, Lee M-C, Mwanzo I, Githeko A and Yan G (2011) Insecticide-treated net (ITN) ownership, usage, and malaria transmission in the highlands of western Kenya. *Parasites & Vectors* **4**, 113.
Baume CA, Reithinger R and Woldehanna S (2009) Factors associated with use and non-use of mosquito nets owned in Oromia and Amhara regional states, Ethiopia. *Malaria Journal* **8**, 264.
Eisele TP, Larsen D and Steketee RW (2010) Protective efficacy of interventions for preventing malaria mortality in children in *Plasmodium falciparum* endemic areas. *International Journal of Epidemiology* **39**(suppl. 1), i88–101.
Eisele TP, Miller JM, Moonga HB, Hamainza B, Hutchinson P and Keating J (2011) Malaria infection and anemia prevalence in Zambia's Luangwa District: an area of near-universal insecticide-treated mosquito net coverage. *American Journal of Tropical Medicine and Hygiene* **84**, 152–157.
Fegan GW, Noor AM, Akhwale WS, Cousens S and Snow RW (2007) Effect of expanded insecticide-treated bednet coverage on child survival in rural Kenya: a longitudinal study. *The Lancet* **370**, 1035–1039.

Filmer D and Pritchett LH (2001) Estimating wealth effects without expenditure data-or tears: an application to educational enrollments in states of India. *Demography* **38**, 115–132.

Futami K, Dida GO, Sonye GO, Lutiali PA, Mwania MS, Wagalla S, Lumumba J, Kongere JO, Njenga SM and Minakawa N (2014) Impacts of insecticide treated bed nets on *Anopheles gambiae* s.l. populations in Mbita district and Suba district, Western Kenya. *Parasites & Vectors* **7**, 63–63.

Galvin KT, Petford N, Ajose F and Davies D (2011) An exploratory qualitative study on perceptions about mosquito bed nets in the Niger Delta: what are the barriers to sustained use? *Journal of Multidisciplinary Healthcare* **4**, 73–83.

Iwashita H, Dida G, Futami K, Sonye G, Kaneko S, Horio M, Kawada H, Maekawa Y, Aoki Y and Minakawa N (2010) Sleeping arrangement and house structure affect bed net use in villages along Lake Victoria. *Malaria Journal* **9**, 176.

Kawada H, Dida GO, Ohashi K, Sonye G, Njenga SM, Mwandawiro C, Minakawa N and Takagi M (2012) Preliminary evaluation of insecticide-impregnated ceiling nets with coarse mesh size as a barrier against the invasion of malaria vectors. *Japanese Journal of Infectious Diseases* **65**, 243–246.

Kilian A, Boulay M, Koenker H and Lynch M (2010) How many mosquito nets are needed to achieve universal coverage? Recommendations for the quantification and allocation of long-lasting insecticidal nets for mass campaigns. *Malaria Journal* **9**, 330.

Larson PS, Minakawa N, Dida GO, Njenga SM, Ionides EL and Wilson ML (2014) Insecticide-treated net use before and after mass distribution in a fishing community along Lake Victoria, Kenya: successes and unavoidable pitfalls. *Malaria Journal* **13**, 466.

Lengeler C (2004) Insecticide-treated bed nets and curtains for preventing malaria. *Cochrane Database of Systematic Reviews* **2**, Cd000363.

Lindblade KA, Eisele TP, Gimnig JE, Alaii JA, Odhiambo F, Ter Kuile FO, Hawley WA, Wannemuehler KA, Phillips-Howard PA, Rosen DH, Nahlen BL, Terlouw DJ, Adazu K, Vulule JM and Slutsker L (2004) Sustainability of reductions in malaria transmission and infant mortality in western Kenya with use of insecticide-treated bednets: 4 to 6 years of follow-up. *JAMA* **291**, 2571–2580.

Minakawa N, Dida GO, Sonye GO, Futami K and Njenga SM (2012) Malaria vectors in Lake Victoria and adjacent habitats in Western Kenya. *PLoS ONE* **7**, e32725.

Minakawa N, Kongere JO, Dida GO, Ikeda E, Hu J, Minagawa K, Futami K, Kawada H, Njenga SM and Larson PS (2015) Sleeping on the floor decreases insecticide treated bed net use and increases risk of malaria in children under 5 years of age in Mbita District, Kenya. *Parasitology* **142**, 1516–1522.

Msellemu D, Shemdoe A, Makungu C, Mlacha Y, Kannady K, Dongus S, Killeen GF and Dillip A (2017) The underlying reasons for very high levels of bed net use, and higher malaria infection prevalence among bed net users than non-users in the Tanzanian city of Dar es Salaam: a qualitative study. *Malaria Journal* **16**, 423.

Ngondi JM, Graves PM, Gebre T, Mosher AW, Shargie EB, Emerson PM and Richards FO (2011) Which nets are being used: factors associated with mosquito net use in Amhara, Oromia and Southern Nations, Nationalities and Peoples' Regions of Ethiopia. *Malaria Journal* **10**, 92.

Noor AM, Moloney G, Borle M, Fegan GW, Shewchuk T and Snow RW (2008) The use of mosquito nets and the prevalence of *Plasmodium falciparum* infection in rural South Central Somalia. *PLoS ONE* **3**, e2081.

Noor A, Kirui V, Brooker S and Snow R (2009) The use of insecticide treated nets by age: implications for universal coverage in Africa. *BMC Public Health* **9**, 369.

Silver JB and Springerlink (2008). *Mosquito Ecology Field Sampling Methods.* Dordrecht: Springer Science + Business Media B.V.

Team RDC (2006) *R: A Language and Environment for Statistical Computing.* Vienna, Austria: R Foundation for Statistical Computing.

Traissac P and Martin-Prevel Y (2012) Alternatives to principal components analysis to derive asset-based indices to measure socio-economic position in low- and middle-income countries: the case for multiple correspondence analysis. *International Journal of Epidemiology* **41**, 1207–1208, author reply 1209–1210.

Wanyua S, Ndemwa M, Goto K, Tanaka J, K'OPIYO J, Okumu S, Diela P, Kaneko S, Karama M, Ichinose Y and Shimada M (2013) Profile: the Mbita health and demographic surveillance system. *International Journal of Epidemiology* **42**, 1678–1685.

World Health Organization (2007) *Long-lasting Insecticidal Nets for Malaria Prevention – A Manual for Malaria Programme Managers*, Trial Edn. *Global Malaria Programme*. Geneva: World Health Organization.

World Health Organization (2014) *The Health of the People: What Works – the African Regional Health Report 2014*. Brazzaville: World Health Organization.

World Health Organization (2015) *Guidelines for the Treatment of Malaria*, 3rd Edn. Geneva: World Health Organization.

World Health Organization (2016) *World Malaria Report 2016*. Geneva: World Health Organization.

Yatsushiro S, Yamamoto T, Yamamura S, Abe K, Obana E, Nogami T, Hayashi T, Sesei T, Oka H, Okello-Onen J, Odongo-Aginya EI, Alai MA, Olia A, Anywar D, Sakurai M, Palacpac NMQ, Mita T, Horii T, Baba Y and Kataoka M (2016) Application of a cell microarray chip system for accurate, highly sensitive, and rapid diagnosis for malaria in Uganda. *Scientific Reports* **6**, 30136.

Zhou G, Li JS, Ototo EN, Atieli HE, Githeko AK and Yan G (2014) Evaluation of universal coverage of insecticide-treated nets in western Kenya: field surveys. *Malaria Journal* **13**, 351.