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ORIGINAL PAPER

The role of dwelling type when estimating the effect of magnetic fields on childhood leukemia in the California Power Line Study (CAPS)

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Abstract

Purpose The type of dwelling where a child lives is an important factor when considering residential exposure to environmental agents. In this paper, we explore its role when estimating the potential effects of magnetic fields (MF) on leukemia using data from the California Power Line Study (CAPS). In this context, dwelling type could be a risk factor, a proxy for other risk factors, a cause of MF exposure, a confounder, an effect-measure modifier, or some combination.

Methods We obtained information on type of dwelling at birth on over 2,000 subjects. Using multivariable-adjusted logistic regression, we assessed whether dwelling type was a risk factor for childhood leukemia, which covariates and MF exposures were associated with dwelling type, and whether dwelling type was a potential confounder or an effect-measure modifier in the MF-leukemia relationship under the assumption of no-uncontrolled confounding.

Results A majority of children lived in single-family homes or duplexes (70%). Dwelling type was associated with race/ethnicity and socioeconomic status but not with childhood leukemia risk, after other adjustments, and did not alter the MF-leukemia relationship upon adjustment as a potential confounder. Stratification revealed potential effect-measure modification by dwelling type on the multiplicative scale.

Conclusion Dwelling type does not appear to play a significant role in the MF-leukemia relationship in the CAPS dataset as a leukemia risk factor or confounder. Future research should explore the role of dwelling as an effect-measure modifier of the MF-leukemia association.

Keywords Childhood leukemia · Residence · Electromagnetic fields · Power lines · Proximity

Introduction

Dwelling is an important factor when considering residential exposure to environmental agents in studies of childhood leukemia. However, it has been little studied in the context of magnetic fields (MF). Type of dwelling (single-family home, apartment, etc.) could affect the MF-childhood leukemia relationship in a number of ways: (1) as a surrogate for other factors, such as socioeconomic status (SES) or radon; (2) as a confounder; (3) through potential exposure misclassification; or (4) as an effect-measure modifier. A directed acyclic graph illustrating these possibilities is presented in Fig. 1.

Dwelling type could be a risk factor for leukemia by acting as a proxy for other unknown or unmeasured exposures. In studies of childhood leukemia, attributes related to a residential dwelling such as the structure, materials, and even age can affect the levels of exposure to gamma radiation or radon gas [1–3]. Previous research has shown both that

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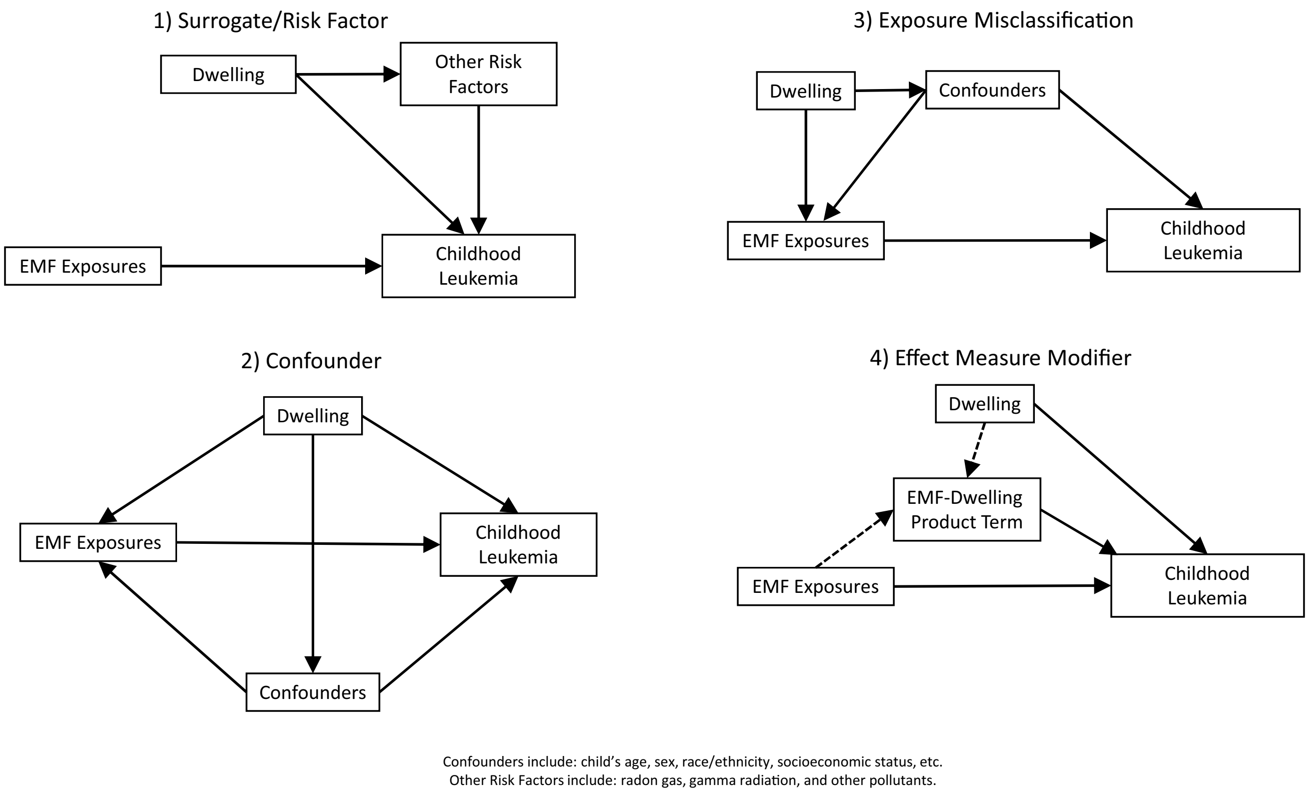

Fig. 1 Directed acyclic graphs depicting possible roles of dwelling in the EMF-leukemia relationship

dwelling type is [4–6] and is not [7, 8] related to childhood leukemia when comparing single-family vs multi-family housing. Type of residence may also affect the MF-leukemia relationship through association with other covariates implicated in MF-childhood leukemia research. Socioeconomic status is associated with dwelling type [9]; dwelling type or home ownership has often been used as a surrogate for SES. Residential mobility, or moving between time of birth and diagnosis, is also associated with dwelling type. When used as a proxy for mobility in adjusting MF-leukemia estimates, we saw a difference in the models excluding dwelling compared to those including it. However, the sample size was limited [10]. Homeownership and dwelling type are also strongly associated with race/ethnicity (US Census Bureau, 2018).

Dwelling type could function as a confounder if it is associated with MF exposures and childhood leukemia (or if it was associated MF exposures and childhood leukemia [11]) beyond the confounding roles of other adjusted variables. Being merely associated with MF exposures and leukemia would not qualify dwelling type as a confounder [12], in which case it could be a collider in an M-bias structure [13]. While two pooled analyses did not show dwelling type to be a confounder in the MF-leukemia relationship [14, 15], residence type has been shown to be a strong predictor of measured magnetic fields [16]. Several studies have found greater exposure to magnetic fields in apartments when using both measurements [2, 17–20] and calculations [6]. Not only can the dwelling type affect the level of MF exposure, it can also affect assessment of said exposure, especially when voltage of, and proximity to, power lines is used to calculate magnetic fields [21]. For example, measured or calculated MF might be higher in a smaller dwelling (apartment) compared to larger dwelling (single-family home). On the other hand, calculated MF may be less accurate for an apartment if its exact location within a structure is unknown. Thus, certain dwelling types (non-single-family homes) are more likely to result in exposure misclassification [6, 10, 22]. To date, there are no data on the association between dwelling type and proximity to overhead power lines.

Previous studies suggest that dwelling type could potentially function as an effect-measure modifier with different strengths of the MF-leukemia association for different dwelling types [10]. The relationship seems to depend on the type of MF exposure: a Swedish study showed stronger association for calculated fields and leukemia in single-family homes despite lower recorded calculated magnetic fields than apartments [6], while a study in Colorado showed lower risks of childhood leukemia when using spot measurements in single-family homes [23]. Both studies showed weaker associations for measured magnetic fields. No recent studies have undertaken such stratified analysis.

In this paper, we explore the role of dwelling type in the MF-leukemia relationship using data from the California Power Line Study (CAPS). The aims of this study are (1) to demonstrate whether dwelling type is a risk factor for leukemia, (2) to investigate which covariates and MF exposures are associated with dwelling type, (3) to examine whether dwelling type behaves as a confounder of the MF-leukemia relationship, and (4) to analyze the role of dwelling type as a potential effect-measure modifier of the MF-leukemia relationship, all under the no-uncontrolled confounding assumption.

Methods

CAPS is a state-wide case–control study that included childhood leukemia cases younger than 16 years of age diagnosed in California between 1988 and 2008. Cases were identified from the California Cancer Registry [CCR; www.ccrcal.org] and matched to the California Birth Registry [CBR; California Department of Public Health, Vital Statistics Branch]. Controls were randomly selected from the CBR and matched to cases 1:1. Controls were excluded if they were diagnosed with any type of cancer in California before the matched case's date of diagnosis. Out of 6,645 eligible childhood leukemia cases identified from the CCR, 4,879 were matched to birth records and had accurate geocoding of birth addresses. Similarly, 4,835 controls met these criteria. Details of this study have been previously described [24]. Exposure assessment for distance to overhead power lines was three-tiered. First, geographic information systems (GIS) information was obtained from electric power companies and distance from home address was calculated for all subjects living within 2000 m (m) of one. Google Earth aerial imagery was used to confirm distance for about a third of the subjects. Finally, for homes within distances close enough to generate non-zero magnetic fields, site visits were conducted to measure the actual distance as well as to collect other relevant information.

In the original CAPS study, residence type was ascertained only for site-visited homes ($n=252$) for whom addresses were available. For this analysis, we obtained information on residence type for 1,799 additional subjects. The 1,799 additional subjects included (1) all subjects with potential for high exposure and (2) a stratified random sample (without replacement), where the stratification was by distance to nearest power line of 200 kV or greater. Sampling weights were calculated as the inverse of the probability of selection. Once these subjects were selected, this sample was combined with the site-visited sample, their order was randomized, and a unique ID was generated for each subject. A dataset that contained only the unique ID, and latitude and longitude were provided to an analyst who used Google Earth and Google Map's Street View to determine dwelling type using the current day image. Only latitudes and longitudes were available as a data protection requirement. Thus, the analyst was blinded to the case–control status of the subjects. Homes were classified as single-family residence, apartment, duplex, or mobile home. In some instances, real estate websites were used to confirm single- vs multi-family home. Additionally, for each subject, a confidence score was recorded (high: the residence was identified and was in the middle of a neighborhood with homogeneous dwelling types; medium: residence not clearly identified, but homogeneous neighborhood; low: unsure of precise location of residence in the mixed neighborhood).

For the main analyses, for the subjects with both site-visited and Google Earth-determined dwelling type, the site-visit information was used. Sensitivity analyses include (1) using all 2,051 observations but with only Google Earth information; (2) using only those with a high-confidence score for dwelling code ($n=1{,}883$); and (3) using only the site-visited subset ($n=252$). Sampling weights were used in all analyses. All models were adjusted for age, sex, SES, and race/ethnicity unless otherwise stated. Multiple imputation was used for observations with missing SES ($n=308$) or race/ethnicity ($n=44$) information. Analyses used all four dwelling types as well as a binary classification in which duplexes and single-family homes were combined into one category and mobile homes with apartments in another. The binary category was based on previous literature showing similar risk estimates for both detached and semi-detached dwellings compared with other types of housing [2, 18, 25, 26]. We also looked at a binary classification where mobile homes, apartments, and duplexes were all considered "non-single-family" residences, but we found duplexes to be more similar to single-family homes for most factors (data not presented).

We first assessed whether dwelling type could be a risk factor (or cause) for childhood leukemia. These analyses used unconditional logistic regression with dwelling type as the exposure variable and leukemia case–control status as the outcome variable. We fit both crude and adjusted models. Next, we examined whether dwelling type was associated with other variables, available to us, that are known to be relevant in the MF-leukemia relationship using Chi-square tests and logistic regression. The variables examined included age, sex, SES, race/ethnicity, maternal age at birth, and mobility. Third, to assess whether dwelling is a confounder beyond confounding adjustment for other variables and under the untestable assumption of no-uncontrolled confounding, unconditional logistic regression was performed using categorical MF exposures as the exposure variables and leukemia case–control status as the outcome, with and without dwelling included in the model. For dwelling to be a confounder given the other adjusted covariates, it would have to be a cause of (and therefore associated with) leukemia (or associated with an unobserved common cause) while being associated with (or a cause of) electromagnetic field (EMF) exposures. This reasoning subsumes a scenario whereby dwelling is a common cause of both EMF exposures and leukemia. We note that there is no statistical test for checking whether a variable is a confounder or not [12, 27] because of the need for the untestable assumption of no-uncontrolled confounding given the adjusted variables. In our analysis here, we merely assessed whether dwelling type was still relevant for confounding adjustment if we assumed no-uncontrolled confounding after adjustment for other measured covariates. Under this strong assumption, if adjusting for dwelling type failed to remove further bias (that is, leading to no change in estimated MF-leukemia relation), then we could assume that dwelling was not an additional confounder. Distance to high-voltage (≥ 200 kV) lines was categorized into 0–< 50, 50–< 200, 200–< 600, 600–< 2000, and 2000 + m (reference). Categories for calculated magnetic fields were as follows: < 0.1 (reference), 0.1–< 0.4, and ≥ 0.4 μT. Finally, to assess whether dwelling is an effect-measure modifier on the multiplicative scale, we conducted unconditional logistic regression analyses stratified by the different dwelling types and examined the estimated relationship between distance and MF exposures and childhood leukemia risk.

Analyses were performed using SAS software version 9.3 (© 2017 SAS Institute Inc.). CAPS was approved by University of California, Los Angeles Office for the Protection of Research Subjects and the State of California Committee for the Protection of Human Subjects.

Results

A majority of children in the 1,799 newly sampled set lived in single-family homes or duplexes (69.7%), which is comparable to the site-visited subset (72.2%). Of the 252 site-visited residences, thirty-four were misclassified using Google Earth inspection (13.5%). Of these, 22 were marked as high-confidence. Eighteen single-family residences were misclassified by the Google Earth inspection, 14 as apartments and 4 as duplexes, with 10 marked as high-confidence. Even after double-checking the 34 discrepant observations using Zillow.com and other such sites, 18 remained misclassified (7.1% of 252).

Childhood leukemia cases appeared less likely to live in mobile homes or duplexes (Table 1); however, results were imprecise. Adjustments left estimates unchanged. No differences in risk estimates were observed when dwelling was dichotomized as single-family homes and duplexes vs apartments and mobiles homes (adjusted odds ratio (OR) 1.04, 95% confidence interval (CI) (0.81–1.33)). There was no difference in results when only Google Earth classification was used or when the analysis was restricted to those with a high-confidence score (results not shown). In the site-visited subset, however, the adjusted odds ratios for childhood leukemia for living in an apartment as compared to a single-family home increased slightly but remained imprecise (Table 1). This increase was also noticeable when dwelling type was binary.

Table 2 shows the relationships of dwelling type with other residential characteristics. As expected, SES, race/ethnicity, and residential mobility were all associated with dwelling type. Those with low SES were more likely to live in housing other than duplex or single-family homes (OR 1.71, 95% CI 1.29–2.28). Similarly, subjects who

Table 1 Risk of childhood leukemia by dwelling type in CAPS (n = 2,051)

Set	Dwelling type	Cases	Controls	COR (95% CI)	AOR (95% CI)[a]
All observations (n = 2,051)	Apartment	293	306	1.06 (0.83–1.36)	1.04 (0.81–1.34)
	Duplex	20	25	0.75 (0.35–1.60)	0.74 (0.34–1.60)
	Mobile Home	9	8	0.68 (0.20–2.27)	0.65 (0.19–2.25)
	Single-Family (reference)	697	693	1.00 (reference)	1.00 (reference)
	Apartment or Mobile	302	314	1.06 (0.83–1.36)	1.04 (0.81–1.33)
	Duplex or Single (reference)	717	718	1.00 (reference)	1.00 (reference)
Site-visited (n = 252)	Apartment	34	35	1.09 (0.62–1.91)	1.31 (0.71–2.44)
	Duplex	2	4	N/A	N/A
	Mobile home	0	1	N/A	N/A
	Single-family (reference)	83	93	1.00 (reference)	1.00 (reference)
	Apartment or mobile	34	36	1.08 (0.62–1.88)	1.29 (0.70–2.38)
	Duplex or single (reference)	85	97	1.00 (reference)	1.00 (reference)

CAPS California Power Line Study, *COR* crude odds ratio, *AOR* adjusted odds ratio

[a]Adjusted for age, sex, socioeconomic status and race/ethnicity. Missing variables multiply imputed

Table 2 Associations of various residential characteristics with dwelling type

Characteristic	Apt + Mob	SFH + Dup	Apt/Mobile Dwelling vs. Duplex/Single-Fam [reference]	
			COR (95% CI)	AOR (95% CI)[a]
Age (years)				
< 2	126	279	0.75 (0.51–1.09)	0.98 (0.77–1.26)
2	102	238	0.71 (0.48–1.07)	0.88 (0.67–1.15)
3	92	229	0.76 (0.51–1.14)	0.98 (0.75–1.29)
4–6	145	366	0.75 (0.53–1.08)	0.98 (0.79–1.23)
7 +	151	323	1.00 (reference)	1.00 (reference)
Sex				
Male	337	797	0.92 (0.72–1.18)	0.97 (0.86–1.10)
Female	279	638	1.00 (reference)	1.00 (reference)
SES				
Low	456	930	1.71 (1.29–2.28)	1.25 (1.07–1.45)
High	139	475	1.00 (reference)	1.00 (reference)
Race/ethnicity				
White	130	475	1.00 (reference)	1.00 (reference)
Black	56	71	2.28 (1.37–3.82)	1.64 (1.03–2.59)
Asian	62	153	1.95 (1.24–3.08)	1.49 (0.97–2.26)
Hispanic	343	687	1.98 (1.47–2.69)	1.36 (0.98–1.86)
Other	7	23	0.63 (0.17–2.30)	0.39 (0.13–1.15)
Maternal Age at Birth (years)				
< 25	248	439	1.26 (0.86–1.86)	1.07 (0.88–1.30)
25–35	293	780	0.97 (0.67–1.40)	0.93 (0.78–1.11)
≥ 35	75	291	1.00 (reference)	1.00 (reference)
Moved				
No	79	311	0.44 (0.30–0.65)	N/A
Yes	223	406	1.00 (reference)	N/A
Exposure: Distance to 200 + kV Line (meters)				
< 50	8	30	0.62 (0.28–1.37)	0.74 (0.39–1.38)
50–< 100	16	41	0.90 (0.51–1.59)	1.03 (0.63–1.67)
100–< 200	33	90	0.85 (0.56–1.29)	0.99 (0.68–1.44)
200–< 600	153	346	1.02 (0.81–1.29)	1.13 (0.87–1.46)
≥ 600	406	928	1.00 (reference)	1.00 (reference)
Exposure: Calculated MF (μT)				
≥ 0.4	6	22	0.63 (0.25–1.57)	0.98 (0.55–1.75)
0.1– < 0.4	18	62	0.67 (0.39–1.15)	0.78 (0.49–1.23)
< 0.1	592	1,351	1.00 (reference)	1.00 (reference)

Dup duplex, *Apt* apartment, *Mob* mobile home, *SFH* single-family home, *SES* socioeconomic status, *kV* kilovolts, *μT* microTesla, *MF* magnetic fields

[a]All models are adjusted for age, sex, SES, and race/ethnicity. Mobility was not included as it is only known for cases. Missing values multiply imputed

were Black, Asian or Hispanic or had moved at least once between birth and diagnosis were also less likely to live in single-family homes. Conversely, living close to high-voltage overhead power lines (OR 0.62, 95% CI 0.28–1.37) and increased calculated fields (OR 0.63, 95% CI 0.25–1.37) were more likely in single-family homes, but these estimates were imprecise. All results were drawn toward the null in the adjusted models (Table 2).

The results of the confounder analysis are presented in Table 3. In the distance analyses, adjustment for dwelling had no effect (both ORs 1.50). The same was true for calculated fields (from OR 1.39 to OR 1.41). The high-confidence

Table 3 Effect of MF exposures on childhood leukemia with and without adjustment for dwelling as a potential confounder (four categories)

Study sample (Subset)	Exposure	Counts		Without adjustment for dwelling	With adjustment for dwelling
	Distance (m)	Cases	Controls		
All 2,051, using site-visit info for 252	< 50	23	15	1.50 (0.88–2.57)	1.50 (0.88–2.58)
	50–< 100	28	29	0.93 (0.60–1.44)	0.94 (0.60–1.45)
	100–< 200	53	70	0.77 (0.54–1.08)	0.77 (0.54–1.08)
	200–< 600	251	248	0.99 (0.78–1.24)	0.98 (0.78–1.24)
	600 +	664	670	1.00 (reference)	1.00 (reference)
1,883 high-confidence	< 50	20	13	1.53 (0.86–2.74)	1.53 (0.85–2.73)
	50– < 100	24	27	0.89 (0.56–1.41)	0.90 (0.57–1.42)
	100– < 200	45	62	0.75 (0.52–1.08)	0.75 (0.52–1.08)
	200– < 600	236	236	1.00 (0.78–1.27)	1.00 (0.78–1.27)
	600 +	612	608	1.00 (reference)	1.00 (reference)
252 site-visited subset	< 50	23	14	1.72 (0.85–3.49)	1.75 (0.84–3.64)
	50– < 100	26	29	0.97 (0.53–1.77)	1.00 (0.53–1.89)
	100– < 200	29	38	0.79 (0.43–1.46)	0.79 (0.41–1.49)
	200– < 600	2	3	N/A	N/A
	600 +	39	49	1.00 (reference)	1.00 (reference)
Study Sample (Subset)	Calculated MF (μT)	Counts		Adjustment for dwelling	With Adjustment for dwelling
		Cases	Controls		
All 2,051, using site-visit info for 252	≥ 0.4	17	11	1.39 (0.82–2.35)	1.41 (0.83–2.38)
	0.1– < 0.4	38	42	0.82 (0.55–1.21)	0.81 (0.55–1.20)
	< 0.1	964	979	1.00 (reference)	1.00 (reference)
1,883 high-confidence	> = 0.4	15	10	1.39 (0.81–2.41)	1.39 (0.80–2.40)
	0.1– < 0.4	32	38	0.79 (0.52–1.19)	0.79 (0.52–1.20)
	< 0.1	890	898	1.00 (reference)	0.79 (0.53–1.20)
252 site-visited subset	≥ 0.4	17	10	1.63 (0.92–2.90)	1.70 (0.95–3.07)
	0.1– < 0.4	37	42	0.81 (0.53–1.25)	0.79 (0.51–1.22)
	< 0.1	65	81	1.00 (reference)	1.00 (reference)

All models adjusted for age, sex, socioeconomic status, and race/ethnicity, using multiple imputations for missing values

MF magnetic fields, *m* meters, *μT* microTesla

subset exhibited the same results, as did the site-visited subset. However, the site-visited subset revealed larger ORs, suggesting that better exposure and confounder assessment may be a factor in the observed results.

Table 4 shows the results of the stratified analyses aimed at assessing whether dwelling type is an effect modifier for the EMF-childhood leukemia relationship. While there are small numbers for apartment and mobile home-dwellers living close to high-voltage lines and in the highest calculated magnetic fields, there does appear to be a difference in strength of association between those who live in duplexes and single-family homes compared to the total. For distance less than 50 m from 200 + kV lines, in the total sample of 2,051 subjects, the OR (95% CI) decreased from 1.50 (0.88–2.57) overall to 1.31 (0.72–2.37) for children living in duplexes and single-family homes. Meanwhile, despite higher calculated fields among those living in duplexes and single-family homes (Table 2), there was no difference in OR compared to the total sample (1.39 vs 1.38, respectively). The high-confidence and site-visited subsets showed similar trends, albeit with greater differences given the smaller sample sizes. Interestingly, the binary classification of single-family home vs non-single-family home showed different results in the site-visited subset of this analysis (Table S1), with the effect estimate for distance in single-family homes dropping to null, while the effect estimate for calculated fields was increased.

Discussion

In this paper, we explored the possible roles of dwelling type on the MF-leukemia relationship. We found no differences in the overall effects when using only Google Earth

Table 4 Odds ratio for childhood leukemia by MF exposures, stratified by dwelling type (as a potential effect-measure modifier)

Study Sample	Distance to 200 + kV lines (m)	Total	Apt/mobile dwelling		Duplex/SFH dwelling	
		OR (95% CI)	ca/co	OR (95% CI)	ca/co	OR (95% CI)
All (n = 2,051)	< 50	1.50 (0.88–2.57)	6/2	N/A	17/13	1.31 (0.72–2.37)
	50– < 100	0.93 (0.60–1.44)	8/8	0.86 (0.35–2.11)	20/21	0.95 (0.56–1.58)
	100– < 200	0.77 (0.54–1.08)	16/17	0.80 (0.39–1.66)	37/53	0.72 (0.48–1.07)
	200– < 600	0.99 (0.78–1.24)	65/88	0.59 (0.35–0.98)	186/160	1.18 (0.90–1.55)
	600 +	1.00 (reference)	207/199	1.00 (reference)	457/471	1.00 (reference)
High-confidence (n = 1,833)	< 50	1.53 (0.86–2.74)	8/1	N/A	12/12	1.05 (0.54–2.04)
	50– < 100	0.89 (0.56–1.41)	5/8	0.55 (0.20–1.50)	19/19	1.05 (0.61–1.79)
	100– < 200	0.75 (0.52–1.08)	13/15	0.63 (0.28–1.44)	32/47	0.74 (0.48–1.13)
	200– < 600	1.00 (0.78–1.27)	60/83	0.55 (0.30–1.01)	176/153	1.21 (0.91–1.62)
	600 +	1.00 (reference)	183/175	1.00 (reference)	429/433	1.00 (reference)
Site-visit (n = 252)	< 50	1.72 (0.85–3.49)	6/2	N/A	17/12	1.33 (0.54–3.30)
	50– < 100	0.97 (0.53–1.77)	6/8	16.87 (4.15–68.58)	20/21	0.90 (0.40–2.01)
	100– < 200	0.79 (0.43–1.46)	7/8	33.27 (8.37–132.25)	22/30	0.65 (0.30–1.41)
	200– < 600	N/A	0/2	N/A	2/1	2.00 (0.21–19.27)
	600 +	1.00 (reference)	15/16	1.00 (reference)	24/33	1.00 (reference)
Study Sample	**Calculated MF (μT)**	**Total**	**Apt/mob dwelling**		**Duplex/SFH dwelling**	
		OR (95% CI)	ca/co	OR (95% CI)	ca/co	OR (95% CI)
All (n = 2,051)	≥ 0.4	1.39 (0.82–2.35)	4/2	N/A	13/9	1.38 (0.77–2.47)
	0.1– < 0.4	0.82 (0.55–1.21)	11/7	0.99 (0.40–2.46)	27/35	0.77 (0.49–1.19)
	< 0.1	1.00 (reference)	287/305	1.00 (reference)	677/674	1.00 (reference)
High-confidence (n = 1,833)	≥ 0.4	1.39 (0.81–2.41)	5/3	N/A	10/7	1.41 (0.73–2.75)
	0.1– < 0.4	0.79 (0.52–1.19)	9/5	1.18 (0.46–3.04)	23/33	0.72 (0.44–1.17)
	< 0.1	1.00 (reference)	255/274	1.00 (reference)	635/624	1.00 (reference)
Site-visit (n = 252)	≥ 0.4	1.63 (0.92–2.90)	4/2	N/A	13/8	1.57 (0.82–3.03)
	0.1– < 0.4	0.81 (0.53–1.25)	11/7	1.16 (0.41–3.28)	26/35	0.75 (0.46–1.24)
	< 0.1	1.00 (reference)	19/27	1.00 (reference)	46/54	1.00 (reference)

All models adjusted for age, sex, socioeconomic status, and race/ethnicity, using multiple imputations for missing values

MF magnetic fields, *Apt* apartment, *Mobile* mobile home, *SFH* single-family home, *ca* cases, *co controls, OR* odds ratio, *CI* confidence interval, *kV* kilovolts, *m* meters, *μT* microTesla

classifications, although there was a possibility of dwelling type misclassification. We do not, however, expect this misclassification to be differential as the analyst was blind to case/control status. Within the smaller, more accurately assessed, site-visited subset, however, apartments and mobile homes were more common in cases, compared to single-family homes and duplexes, after adjusting for age, sex, SES, and race/ethnicity.

As expected, dwelling type was associated with both race/ethnicity and SES, although Schuz et al. found that residence type only appeared to be associated with other measures of SES in urban areas compared to rural areas [19]. Our study had no information on urban/rural status. However, Tomitsch et al. reported that differences between urban and rural areas could be explained by residence type [20], so we did not seek this information to be included in the model when both SES and dwelling type were present. Neither age nor maternal age at birth was associated with dwelling type.

Most previous findings for measured fields showed higher MF in non-single-family dwellings [2, 17, 19, 20], whereas our results showed the opposite. While we used calculated fields, based on the voltage of and distance from nearby overhead power lines, our findings were still contrary to a previous study using calculated fields [6]. On the other hand, Table 2 shows that close proximity to higher-voltage lines was also less common among non-single-family residences, consistent with previous studies [25]. Compared to a previous California study where over 80% of subjects lived in single-family homes [28], the subjects in this study were more likely to live in apartments (29.2%). As mentioned previously, exposure assessment is limited in apartment dwellings, and calculations are often not as accurate [6].

We did not find evidence of additional confounding by dwelling for either distance or magnetic fields, under our assumption of no-uncontrolled confounding [29]. Similarly, dwelling type did not affect a previously observed multiplicative interaction between calculated fields and distance [30], although numbers were small. These observations were consistent with previous findings for dwelling type in pooled analyses [14, 15]. Our results were slightly higher for proximity to power lines (OR 1.50) and slightly lower for the highest calculated fields (OR 1.39) due to the dwelling sample subset compared with previous studies [31, 32]. These results, combined with the elevated effect estimates in the site-visited subset, suggest that the ability to detect an association, should one exist, may depend on the quality of exposure assessment.

Furthermore, we found possible effect-measure modification by dwelling type when comparing the MF-leukemia relationship in those who lived in single-family homes compared to those who did not. Due to small numbers, however, the results were extremely imprecise and it remains to be seen whether the finding is replicated in future studies. The two exposures revealed different trends, with distance showing weaker associations in single-family homes and calculated fields remaining mostly unchanged. This, too, was in contrast to some previous findings which showed an OR of 5.6 for exposure to calculated fields ≥ 0.2 μT in single-family homes, but only 1.1 in apartments [6].

Strengths of our study include the use of population registries for identification of cases and controls, avoiding participation bias and exposure and confounder assessment blind to case–control status to reduce information bias. However, misclassification of dwelling type and magnetic field exposure is possible, especially since only latitudes and longitudes were available, but we do not expect such misclassification to be differential with respect to case/control status. Additionally, while we attempted to estimate calculated fields and distance using historical data, we did not ascertain dwelling types in actual birth years. Although no historical information was used to determine dwelling type, we do not expect the neighborhood types to have changed, as that would require zoning changes. Additionally, in a Canadian study comparing wire coding over a span of fifteen years, only 2% of homes underwent some form of construction [33], but only two changed from single family to apartments (JJ Spinelli, personal communication). Again, we do not expect this bias to be differential and changes of residences from apartments to single-family homes are uncommon. Another limitation was small sample sizes for our effect modification analysis. Even with dwelling types grouped together, the numbers in the highest exposed categories remained small. Interaction effects between the MF exposures and dwelling type should be studied in future analyses where the sample size allows.

In conclusion, dwelling type does not appear to play a significant role in the MF-leukemia relationship in the CAPS dataset as a risk factor or confounder, beyond other commonly adjusted for covariates, provided no-uncontrolled confounding. As mentioned previously, different countries have different types of building structures, materials, and electrical wiring practices. Accurate exposure and confounder assessment are crucial to the study of this matter. Future research should explore the role of dwelling as an effect modifier and potential interaction effects.

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