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Abstract

Objective: Although there is a growing body of literature on sample size in multilevel or hierarchical modeling, few studies have examined the impact of group size < 5.

Design: We examined the impact of a group size less than five on both a continuous and dichotomous outcome in a simple two-level multilevel model utilizing data from two studies.

Setting: Models with balanced and unbalanced data of group sizes 2 to 5 were compared to models with complete data. Impact on both fixed and random components were examined.

Results: Random components, particularly group-level variance estimates, were more affected by small group size than were fixed components. Both fixed and random standard error estimates were inflated with small group size. Datasets where there are a large number of groups yet all the groups are of very small size may fail to find or even consider a group-level effect when one may exist and also may be under-powered to detect fixed effects.

Conclusions: Researchers working with multilevel study designs should be aware of the potential impact of small group size when a large proportion of groups has very small (< 5) sample sizes.

INTRODUCTION

With the growing availability of linked individual- and community-level data, investigators may find themselves with many places sampled throughout a country but few respondents per contextual group (be it neighborhood or other grouping) (1). The degree to which this occurs will of course depend on the level of grouping and survey design, but will be most pronounced when the census tract or block group is utilized.

In general, it has been shown that when interested in a higher-level, contextual effect (i.e., between-group variance) the number of groups appears to be more important in a multilevel analysis than the group size (2, 3). Although there is a growing body of literature on the effects of group size (i.e., number per group) and on the number of groups in multilevel or hierarchical modeling (4-8), few studies have examined the impact of group sizes less than five (1). As Clarke points out, such situations are increasing due to the availability of geographically-referenced national survey data and multilevel studies that will follow. Clarke found, using Monte Carlo simulated data, that two-level multilevel models can be reliably estimated with small group sizes of an average of only five observations per group; however, with extremely small group sizes, group level variance estimates may be overestimated. Disaggregating the multilevel design may increase the risk of Type I error.

Our objective was to examine the impact of a group size less than five on both fixed and random components in a simple two-level multilevel model, with a sufficient number of groups to test random slope variances (3, 9-11). While like Clarke (1) we also use continuous and dichotomous outcomes, balanced and unbalanced data, and examine extremely small group sizes, we focus on both the fixed as well as random components and based simulations on real data with two different group sizes.

METHODS

We utilize data from two multilevel studies in the United States, both with information on body mass index (BMI). One study examined influences on BMI with data obtained from Louisiana driver's license records from 1997 and included 223,747 nested in 459 census tracts (taken as the "neighborhood" unit). The second study included BMI data on 2881 randomly sampled individuals from 217 census tracts in Louisiana and Los Angeles County, California surveyed between 2004 and 2005.

Outcomes

BMI was determined using reported heights and weights and calculated using the Centers for Disease Control (CDC) formula[1] (i.e., (weight in pounds / (height in inches)^2) X 703). BMI was examined as a continuous outcome of interest, while overweight or obesity was examined as a dichotomous outcome. Overweight or obesity was defined as a BMI of 25 or greater. According to CDC definition, an adult who has a BMI between 25 and 29.9 is considered overweight; a BMI of 30 or higher is considered obese.

BMI and obesity / overweight were chosen as outcomes given their universal measurement across studies utilized and the fact that BMI has been shown to have a moderately high (e.g., > 4.0%) intraclass correlation coefficient (ICC) in our previous research. Group-level influences on individual outcomes are often expressed as the ICC, calculated for our linear model as:

[1] BMI defined by CDC in:. http://www.cdc.gov/nccdphp/dnpa/bmi/index.htm,

$$\frac{V_{neighborhood}}{V_{neighborhood} + V_{individual}} \times 100\%$$

where $V_{neighborhood}$ = variance between census tracts or neighborhoods and $V_{individual}$ = variance among individuals within neighborhoods. An ICC at or above 2% is suggestive of a potential higher level effect (e.g., neighborhood) and worth examining in a multilevel framework (12).

The prevalence of obesity or overweight in the DMV study sample was 48.1% and mean BMI (SD, one standard deviation) was 25.5 (5.1). The prevalence of obesity or overweight in the Alcohol Marketing study was 59.1% (58.6% in CA and 59.6% in LA respondents) and mean BMI was 27.0 (6.0).

Independent Variables

While the primary models examined were empty random coefficient models (i.e., no independent variables included), to determine the impact on basic random and fixed components we also ran models with one group-level covariate, socioeconomic status (SES), and individual age in years as the individual covariate. SES and age were chosen given their association with BMI in previous research and availability across the two data sets. The socioeconomic index was calculated for all tracts as the sum of z-scores of three factors in the U.S. Census: % with less than high school education, % living in poverty, and % of males not in the labor force.

Simulation Models and Procedures

Two primary simulations were performed using data from both studies and two different models, one a linear random coefficients model (BMI as outcome) and one a logistic random coefficients model (obesity or overweight as outcome). All analyses were conducted in SAS version 9, with PROC MIXED used for continuous and PROC GLIMMIX for dichotomous outcomes. Restricted maximum likelihood (REML) estimation was employed for all models.

Variations in group size were based on randomly sampling the number per tract using PROC SURVEYSELECT. The simulations included: a) holding the group size constant *for all study census tracts* and varying the size from 2 to 5 within tracts, and b) setting the group size to five or less for a portion—5, 10, 25, 50, 75, and 90 %—of the tracts and varying the size within those tracts from 2-5 individuals per tract. Simulations were run on 1) the empty linear and logistic models, 2) linear and logistic models with a group-level covariate (SES), and 3) linear and logistic models with an individual-level covariate (age). Five samples / simulations were run for each combination and the average estimates taken.

In all models particular attention was paid to the estimates and standard errors for both the fixed and random components, including measures of the group- or tract-level influence or the variance in individual outcomes that can be attributed to differences between census tracts or groups (3, 12). These measures are particularly useful when examining group-level influences on health or other outcomes.

For the logistic model, the ICC was calculated by following the linear threshold model or latent variable model method formula of Snijders (3) based on an underlying continuous variable with $V_{individual} = \Pi^2 / 3$ (i.e., 3.29). This assumes that the unobserved individual variance follows a logistic distribution, so that the variance of a standard logistic distribution is $\Pi^2 / 3$. However, the pseudo ICC for non-linear models may be difficult to understand in epidemiological terms and therefore we also calculated and examined the Median Odds Ratio (MOR) as described by Merlo and colleagues (13). The MOR, like the ICC calculation using the linear threshold model method, is independent of the prevalence of the outcome. It represents the median value of the odds ratio for all possible comparisons of individuals from a lower to higher risk area. High group-level variation in the risk (i.e., greater group-level influence) would result in higher MOR values, while low group-level variation in risk would result in lower MOR values (i.e., close to 1.0). The MOR was calculated as:

$$\exp[\,0.95(\sqrt{V_{neighborhood}})]$$

where $V_{neighborhood}$ = variance between neighborhoods.

RESULTS

Table 1 presents the results of the empty random effects linear regression model from the DMV study data, with the full sample results included in the first column. The average number of individuals per tract was 447 (range = 4 – 1549). With all sampled subjects per tract included, a significant amount of the variance in BMI was apportioned to the census tract or neighborhood level, evidenced by the ICC (4.23%). As shown in the second through fifth columns, inflated standard errors in both fixed and random components were evident when all tracts have two, three, four, or five individuals per tract. With respect to the fixed parameter estimates, a small group size appeared to have little impact on the intercept.

The amount of bias observed in the variance components of the random effects, however, was not negligible. As more individuals were added to the tract, the amount of variation from the full sample observed in variance components estimates was greatly reduced and differences in either direction were observed. One key observation, however, was that the between-tract random variance component only became significant when the group size reached five per group (Z = 3.22, two-sided $P < 0.05$).

Table 1 also presents the results of the empty random effects logistic regression model from the DMV study data, with the full sample included in the first column. Results are similar to those observed for the linear outcome, with upward differences of more than 100% in standard error components of both the fixed and random effects when all tracts had two to five individuals per tract. With smaller group sizes, the variance estimates tended to be lower than those for the full study population, with the greatest differences observed for between-tract variance.

Although not shown, when a neighborhood-level measure (SES) was added to the linear or logistic regression empty models, differences in fixed and random component estimates and standard errors patterns were identical to those seen in the empty models. Similar results were also seen when the individual-level factor of age was added to the models.

Area of residence again appears relevant for understanding variations in individual BMI and obesity and overweight patterns in the Alcohol Marketing Study data, as shown in the first columns of Table 2 for linear and logistic models (ICC=4.32% and MOR=1.10). The average group size in this original data was 16 (range = 1 – 50). Observed differences in fixed and random component standard error, variance and parameter estimates in this study data was nearly identical to that seen in the DMV study data as the number of individuals per tract *for all tracts* was varied from two to five.

However, even with a group sample size of five, the between-tract variance estimates were not significant (compared to the full model). Although not shown, results from models that include a tract-level (SES) or individual-level (age) variable were also similar to DMV study data in their impact on estimates.

Because it would rarely be the case that *all* groups would have very small sample sizes (e.g., all with only 2 individual per tract), we ran more realistic simulations where we varied the proportion of all tracts that were randomly sampled to yield two to five individuals per tract. Table 3 presents the results of the empty linear regression random coefficients model for BMI from the DMV Study data, with 2 people randomly sampled per tract for 10, 25, 50, 75 and 90% of tracts. Comparing results in columns 2 – 6 of Table 3 to the full model results in column 1, the observed differences seen in fixed and random components are similar in direction to those seen when all tracts had two to five respondents, although not as drastic. With only 10% of tracts with two individuals per tract, standard error estimates for fixed effects exhibited a difference of less than 10%. As the group size decreased across tracts with an increasing proportion of tracts with two individuals per tract, the inflation in the standard errors became greater. Differences in the standard error of random components were also observed and greatest when 50 to 90% of tracts had only two individuals per tract. In comparison, upward biases observed in the fixed and random parameter estimates were all less than 5-10%, with greater biases observed when a greater proportion of the tracts had only two individuals per tract. When 90% or more of tracts had only two individuals per tract, the ICC was more than 25% higher than in the original full model.

As shown in the bottom half of Table 3, the observed differences in the logistic regression model were somewhat similar to those in the linear model in terms of the impact on fixed effects and the inflation of standard errors.

Shown in Table 4 are the results from the linear random effects model from the DMV Study data, with the addition of a group- (SES) and individual-level (age) covariate to models with two individuals per tract for 10 to 90% of tracts. The great reduction in explained group-level variance with SES added to the model was similar across simulations from 10 to 90%. Nonetheless, the differences observed in these models as the proportion of tracts with two individuals per tract increased resulted in similar changes to the fixed and random component standard errors and parameter estimates. In terms of a group-level effect, even with 90% of the tracts having two individuals per tract, the between-tract variance remained significant (Z = 6.92), albeit substantially lower than that seen in the full model.

The same trends were observed when an individual-level covariate (age) was added to the empty models, as shown in the bottom panel of Table 4. We also examined results when both an individual and group-level covariate were added to the empty models and findings were similar, although standard errors became even more inflated as a greater proportion of tracts had a small (n=2) group size. Inflation of the standard errors was even more apparent when additional covariates were added to the models (data not shown).

Although not shown, the results of models from DMV Study data where 10 to 90% of tracts had three, four, or five individuals per tract were very similar to those seen by randomly selecting two individuals per tract, with inflated standard error estimates and minimal bias in the fixed parameter and random variance estimates.

Similar models with the number of individuals per tract (two to five) varied for five to 90% of tracts were run with data from the Alcohol Marketing Study. Results revealed that the magnitude and direction of observed differences were nearly equivalent to those observed with the DMV Study data, albeit not as consistent. As was the case with the DMV Study data, differences in fixed and random components were greatest when 50% or more of tracts had only two individuals per tract, particularly for between-tract variance component estimates.

Similar differences were observed for the logistic model. Biases in the ICC and MOR for the logistic models were minimal.

DISCUSSION

In general, the fixed effects parameter estimates, including models with intercept alone as well as with covariates included, do not appear to be affected by small group size. Random components appear to be more impacted by small group size, with upward bias in the random between-group variance component estimates and downward bias in the within-group variance component estimates observed in this study. Not until a group size of five was the between-tract random variance component significant even with 459 groups, at a relatively high ICC (4.23%). In the Alcohol Marketing Study, however, even with all groups at a group size of five, the between-tract variance estimates were still not significant, perhaps reflecting the smaller number of groups (N=217) in that study.

Large differences in the standard errors of both fixed and random components were apparent. While somewhat expected due to decreasing sample size, given the lack of a generally applicable formula for the standard error with REML estimators (2), it is difficult to tell whether the inflation is beyond what would be expected by increasing sample error. As the group size increased, the standard errors (for both fixed and random components) and random variance estimates begin to approach those seen in the full data sets.

Our conclusion of small group size's impact on fixed parameter effects is similar to Clarke's (1), however, we find differences with respect to the effect on standard error estimates and to random components. While this study is not without its limitations and assuming that our number of groups is sufficiently large, our findings have implications for research into not only group-level effects on individual outcomes, but also on individual-level factors. With respect to group-level effects, if the ICC or MOR or equivalent measure is used as the primary judge of the relative importance of a neighborhood-level risk factor, then conclusions will depend on the type of outcome and regression model. When all (or nearly all) groups have a small group size, the ICC calculation is biased either upward or downward. This noise could be due to the use of real data. The ICC or MOR does not appear to be as impacted by small group size in the case of the logistic model with the latent variable approach (3) for ICC calculation in a logistic model.

Beyond the ICC or MOR estimates, however, is the case of even considering group-level effects. If a substantial proportion of groups have a small number per group so that the standard error of the random between-group variance is inflated to the degree that an insignificant between-group variance is observed, then researchers may conclude (despite the value of the ICC or other measure of clustering) that there is no group-level effect or that there is no need to consider a group-level factor (or multilevel analysis) when, in fact, there may be. This would have implications for the type of analyses chosen as well as conclusions drawn and may be even more important when the number of groups is small. Such conclusions would lead one to perhaps disaggregate into traditional ordinary least squares or logistic regression, which would result in increased risk of Type I error (1).

Results suggest that with group sizes of less than five, the between-tract random variance component may fail to reach statistical significance, even for a relatively high ICC or when one may expect a group-level effect. Such a situation could very well occur once data is stratified or a particular subgroup of the population is singled out, e.g. black female adolescents. To examine what would happen with an even smaller number of groups and small group size we ran additional simulations. Using the same simulations in terms of the proportion of tracts with a group size of 2 to 5 and an overall number of groups of 20 and 30, inflation (i.e., > 100%) in the between-group standard error compared to the full model with 20 or 30 per group begins even with 5% of tracts having a group size of two.

If the significance of a fixed component parameter estimate is used to judge the importance of a group-level effect, our findings suggest that such inferences may be under-powered with small group size. The same would hold true for individual-level fixed effects parameters, given the inflated standard errors of fixed effects components. While the number of groups remains important when investigating group-level or contextual effects, the group size should also be taken into account. Researchers working with multilevel study designs should be aware of the potential impact of small group size when a large proportion of groups has very small (< 5) sample sizes.

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Table 1.

Impact of Group Size on Empty Model for Body Mass Index from DMV Study Data – Linear Random Effects Model

	N per Census Tract (N = 459 tracts)				
	n=4-1549, average=447 [a]	**n=2**	**n=3**	**n=4**	**n=5**
Intercept	**25.5985**	25.7111	25.6808	25.7215	25.4540
Standard error	**0.05143**	0.1689	0.1469	0.1286	0.1193
Random Effects					
Variance between tract intercepts	**1.1357**	0.6290	1.5899	0.9898	1.4914
Standard error	**0.08023**	1.1940	0.7607	0.5609	0.4625
Variance within tracts	**24.5154**	24.9286	24.9366	26.3888	25.1619
Standard error	**0.07378**	1.6455	1.1639	1.0057	0.8314
ICC	**4.23%**	2.46%	5.99%	3.62%	5.60%

Impact of Group Size on Empty Model for Obesity or Overweight in DMV Study Data – Logistic Random Effects Model

	N per Census Tract (N = 459 tracts)				
	n=4-1549, average=447 [a]	**n=2**	**n=3**	**N=4**	**n=5**
Intercept	**0.4851**	0.4760	0.4891	0.4975	0.4984
Standard error	**0.004124**	0.01143	0.01689	0.01388	0.01191
Random Effects					
Variance between tract intercepts	**0.007068**	0.01244	0.01160	0.007630	0.003407
Standard error	**0.000515**	0.004259	0.01170	0.006959	0.004902
Variance within tracts	**0.2431**	0.2371	0.2386	0.2426	0.2467
Standard error	**0.000732**	0.007835	0.01575	0.01132	0.009403
ICC [b]	**0.21%**	0.38%	0.35%	0.23%	0.10%
Median Odds Ratio (MOR) [b]	**1.08**	1.11	1.11	1.09	1.06

[a] Based on full sample of individuals included in study, range and average per tract. Other individuals per tract (group size) randomly selected.
[b] ICC with individual-level variance calculated using the formula of Snijders based on an underlying continuous variable with $V_{individual} = \Pi^2 / 3$ (Snijders and Bosker, 1999). Because of limitations of the ICC for non-linear outcomes, the Median Odds Ratio (MOR) (Merlo et al., 2004) was also calculated.

Table 2.

Impact of Group Size on Empty Model for Body Mass Index from Alcohol Marketing Study Data – Linear Random Effects Model

	N per Census Tract (N = 217 tracts)				
	n=1-50, average=16 [a]	**n=2**	**n=3**	**n=4**	**n=5**
Intercept	27.0348	26.8738	27.1318	26.8479	25.4540
Standard error	0.1465	0.2143	0.2903	0.2600	0.1193
Random Effects					
Variance between tract intercepts	1.5583	1.8189	1.6542	1.2718	1.1198
Standard error	0.4235	1.0458	2.5502	1.7727	0.9656
Variance within tracts	34.5218	28.0653	28.8118	35.0699	34.9479
Standard error	0.9945	1.6925	3.2001	2.6582	1.8412
ICC	4.32%	6.22%	5.43%	3.50%	3.10%

Impact of Group Size on Empty Model for Obesity or Overweight in Alcohol Marketing Study Data – Logistic Random Effects Model

	N per Census Tract (N = 217 tracts)				
	n=1-50, average=16 [a]	**n=2**	**n=3**	**n=4**	**n=5**
Intercept	0.5924	0.6125	0.5770	0.5814	0.5658
Standard error	0.01203	0.02674	0.01793	0.01898	0.02136
Random Effects					
Variance between tract intercepts	0.01062	0.03737	0.01489	0.01072	0.008022
Standard error	0.002948	0.01843	0.007045	0.008200	0.01115
Variance within tracts	0.2314	0.2008	0.2295	0.2330	0.2381
Standard error	0.006683	0.02139	0.01210	0.01401	0.01757
ICC [b]	0.32%	1.12%	0.45%	0.33%	0.24%
Median Odds Ratio (MOR) [b]	1.10	1.20	1.12	1.10	1.09

[a] Based on full sample of individuals included in study, range and average per tract. Other individuals per tract (group size) randomly selected.
[b] ICC with individual-level variance calculated using the formula of Snijders based on an underlying continuous variable with $V_{individual} = \Pi^2 / 3$ (Snijders and Bosker, 1999). Because of limitations of the ICC for non-linear outcomes, the Median Odds Ratio (MOR) (Merlo et al., 2004) was also calculated.

Table 3.

Impact of Group Size = 2 on Empty Model for Body Mass Index from DMV Study Data – Linear Random Effects Model

	% of Tracts with 2 per Tract					
	n=4-1549, average=447 [a]	**10**	**25**	**50**	**75**	**90**
Intercept	**25.5985**	25.5846	25.6379	25.5653	25.5716	25.5981
Standard error	**0.05143**	0.05456	0.05745	0.09219	0.07099	0.1269
Random Effects						
Variance between tract intercepts	**1.1357**	1.1627	1.0892	1.1609	1.1772	1.4113
Standard error	**0.08023**	0.08646	0.08977	0.1715	0.1185	0.2936
Variance within tracts	**24.5154**	24.4896	24.7601	24.2987	24.1826	23.9069
Standard error	**0.07378**	0.07781	0.08556	0.1480	0.1033	0.2249
ICC	**4.23%**	4.53%	4.21%	4.56%	4.64%	5.58%

Impact of Group Size = 2 on Empty Model for Obesity or Overweight in DMV Study Data– Logistic Random Effects Model

	% of Tracts with 2 per Tract					
	n=4-1549, average=447 [a]	**10**	**25**	**50**	**75**	**90**
Intercept	**0.4851**	0.4842	0.4881	0.4832	0.4793	0.4826
Standard error	**0.004124**	0.004407	0.004588	0.005821	0.007696	0.01132
Random Effects						
Variance between tract intercepts	**0.007068**	0.007329	0.006646	0.007447	0.007256	0.009267
Standard error	**0.000515**	0.000562	0.000562	0.000767	0.001072	0.002099
Variance within tracts	**0.2431**	0.2429	0.2436	0.2423	0.2427	0.2421
Standard error	**0.000732**	0.000772	0.000842	0.001035	0.001478	0.002276
ICC [b]	**0.21%**	0.23%	0.20%	0.23%	0.22%	0.28%
Median Odds Ratio (MOR) [b]	**1.08**	1.09	1.08	1.09	1.08	1.10

[a] Based on full sample of individuals included in study, range and average per tract. Other individuals per tract (group size) randomly selected.
[b] ICC=Intraclass correlation coefficient (with individual-level variance calculated using the formula of Snijders based on an underlying continuous variable with $V_{iindividual} = \Pi^2 / 3$ (Snijders and Bosker, 1999). Because of limitations of the ICC for non-linear outcomes, the Median Odds Ratio (MOR) (Merlo et al., 2004) was also calculated.

Table 4.

Impact of Group Size = 2 on Model with *Group*-Level Covariate – DMV Study Data – Linear Random Effects Model

		% of Tracts with 2 per Tract				
	n=4-1549, average=447 [a]	**10**	**25**	**50**	**75**	**90**
Intercept	**25.6206**	25.6145	25.6040	25.5767	25.6515	25.6802
Standard error	**0.02956**	0.03132	0.03530	0.05929	0.04532	0.07760
Socioeconomic status	**-0.3380**	-0.3303	-0.3295	-0.3475	-0.3257	-0.4009
Standard error	**0.01119**	0.01181	0.01347	0.02204	0.03657	0.03186
Random Effects						
Variance between tract intercepts	**0.3318**	0.3367	0.3614	0.3602	0.4046	0.4377
Standard error	**0.02611**	0.02780	0.03232	0.05586	0.04480	0.06324
Variance within tracts	**24.5155**	24.5673	24.5051	24.2583	24.8719	23.4227
Standard error	**0.07378**	0.07795	0.08487	0.1439	0.1055	0.2140
ICC	**1.34%**	1.35%	1.45%	1.46%	1.60%	1.83%

Impact of Group Size = 2 on Model with *Individual*-Level Covariate – DMV Study Data – Linear Random Effects Model

		% of Tracts with 2 per Tract				
	n=4-1549, average=447 [a]	**10**	**25**	**50**	**75**	**90**
Intercept	23.5233	23.5213	23.5327	23.4005	23.4115	23.7263
Standard error	0.06094	0.06374	0.06995	0.08502	0.1127	0.1660
Age	0.05020	0.05009	0.04993	0.05285	0.05211	0.05018
Standard error	0.000712	0.000752	0.000823	0.001023	0.001514	0.002294
Random Effects						
Variance between tract intercepts	1.2290	1.2071	1.2267	1.2260	1.0492	1.1383
Standard error	0.08616	0.08915	0.1000	0.1231	0.1514	0.2641
Variance within tracts	23.9728	23.9254	24.0049	23.6985	24.2722	25.1346
Standard error	0.07214	0.07606	0.08366	0.1022	0.1553	0.2396
ICC	4.89%	4.80%	4.86%	4.92%	4.14%	4.30%

[a] Based on full sample of individuals included in study, range and average per tract. Other individuals per tract (group size) randomly selected.