The Effects of Individual-Level Random Measurement Error on Group-Level Correlations

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ABSTRACT

This study addresses the effects of individual-level random measurement error in research that examines relationships between group-level constructs aggregated from the responses of individual group members. Simulation data show that the effects of measurement error vary greatly depending on levels of group size, scale length, true between-group variability, and effect size. Even very low levels of measurement error, for instance, can produce significantly attenuated correlations between group-level variables when group size is low, number of items composing a scale is small, true between-group variability is low, and effect size is large. Conversely, correlations between group-level constructs would remain unbiased even at very high levels of measurement error when group size, scale length, and true between-group variability are large.

INTRODUCTION

The academicians from a wide variety of disciplines (e.g., Information Systems, Marketing, Management) are increasingly interested in the group-level phenomena (House, Rousseau, & Thomas-Hunt, 1995; Klein & Kozlowski, 2000). The researchers are seeking to understand the relationships that exist between, for example, such constructs as group cohesion and group performance, group size and intra-group decision making, group emotional intelligence and group conflict resolution. Quantification of the aforementioned and other theoretical relationships, oftentimes and first, calls for the aggregation, typically via average, of the individual responses within each of the groups, to represent each of the group-level constructs that can only be assessed at the group member level. These aggregated scores, i.e., group means, are then used to compute a correlation, which is, perhaps, the most commonly used measure of strength and direction of the inter-variable relationship. The representativeness of the computed correlation coefficient is a function of several factors, the most major of which is, of course, the extent to which the process of measurement employed in obtaining individual scores is free from error (Weisberg, 2005).

Generally speaking, the research errors may be broken into two categories: sampling (Pedhazur & Schmelkin, 1991, pp. 320-321) and non-sampling (Iachan, 1983), with non-sampling error being the major contributor to a total survey error (Assael & Keon, 1982). Biemer & Lyberg (2003) identify five components of non-sampling error: specification, frame or coverage, processing, non-response, and measurement. Among the five non-sampling errors, measurement error (i.e., incorrect answers) and non-response error (i.e., missing data) are deemed as the most severe (Assael & Keon, 1982) with non-response error holding the top spot when it comes to the amount of bias it contributes to the empirical findings (Sjostrom, Holst, & Lind, 1999). Despite an enormous size of multidisciplinary group-level literature, there are only two papers (Allen, Stanley, Williams, & Ross, 2007; Timmerman, 2005) that address the effect of within-group non-response on the group-level correlations and there is no research that studies the effect of individual-level random measurement error on the group-level correlations.

Regarding the latter (i.e., individual-level random measurement error) an argument can be made, on the basis of the classical test theory, that individual-level random measurement error should, statistically, have no effect on the group-level correlations. Classical test theory holds that individual score is composed of true score plus the error score, with the error score having an expected value of 0 (for detailed explanation, please refer to Pedhazur & Schmelkin, 1991, pp. 83-84). Thus, in the process of aggregation, i.e., when individual scores are averaged to represent a group-level score, the individual-level random measurement error should "wash" away, leaving only the unbiased group mean. And, consequently, unbiased group means would keep the correlations between group-level variables unbiased also. This rationale, although plausible, requires an investigation, because most groups studied typically number anywhere from 3 to 15 group members and it is reasonable to expect that individual random errors of the measures of 3 or even 15 group members, when averaged, would equal to a number that is different from 0. Hence, the objective of this research is to investigate if, how, and under what circumstances individual-level random measurement error would bias group-level correlations.

This paper unfolds as follows. First, the process via which individual random measurement error would bias group-level correlations is presented. Second, the effect that salient variables, such as group size, number of items used to measure a construct, true between-group variability, and true effect size (i.e., true correlation), would have in conditioning the operation of the measurement error on group-level correlations is examined. Third, the choice of the method and the method itself are outlined. Fourth and last, results and their implications are discussed.

THE PROCESS VIA WHICH MEASUREMENT ERROR OPERATES

Individual group member score is composed of the true score and the error score. Practically, for groups that are sized anywhere between 3 and 15, the average of the error scores would be different from 0. That is, the average of those scores will be some number, either positive or negative, and the extent to which this number will be close to 0 is a function of a magnitude of the variance of individual error scores. If the variance of the individual error scores is high, then the average of the individual error scores, on average, will be further from 0, then when the variance of the individual error scores is low. In essence, every group-level score, aggregated from individual group members' responses, because groups are generally small, contains some level of bias or error. The variability of these biases is the error variance of the group-level variable. And, all other factors being held constant, the relationship between the variance of the individual error scores and the error variance of the group-level variable is direct. That is, when the variance of the individual-level errors increases, the error variance of the group-level variable increases also. In other words, the greater the variance of the individual error scores, the further the observed group mean, on average, would deviate from the true group mean, which, consequently, would result in increasing error variance of the group-level variable.

Increasing error variance of the group-level variable, due to increasing variance of the individual group members' error scores, would undermine the reliability of the group-level measure. Reliability may be defined as the extent to which a measure is free from error (Pedhazur & Schmelkin, 1991, p. 82), and reliability, formulaically, is true-score variance divided by total variance, with total variance being the sum of true-score and error variances (Allen & Yen, 2002). Therefore, as the error variance of the group-level measure increases, the reliability of the group-level measure should decrease.

The observed correlation between two group-level measures is a function of the true correlation between these group-level measures and their reliabilities. Specifically, the observed correlation between two group-level variables equals true correlation multiplied by the square root of the product of reliabilities for each of these group-level variables (Pedhazur & Schmelkin, 1991, p. 113). This research considers a scenario where the independent group-level variable is aggregated from individual responses, whereas the dependent group-level variable is objectively measured. Therefore, the reliability of the outcome variable remains constant, whereas the reliability of the independent variable decreases as the error variance increases. And, decreasing reliability of the aggregated variable should correspond to decreasing observed correlation between group-level variables.

In summary, increasing variance of individual error scores (i.e., increasing individual measurement error) attenuates the observed correlation between two group-level variables by deviating the observed averages, computed from each group, from true group averages, thereby creating error variance. This error variance, in turn, attenuates the reliability of the aggregated group-level variable, and, this decreasing reliability, in turn, leads to the attenuation of the observed correlation. The model shown in Figure 1[1] summarizes this three-stage meditational process.

POTENTIAL MODERATORS OF MEASUREMENT ERROR EFFECTS

It seems probable, that the effect of individual measurement error does not operate outside of influence of its context and there are factors that could interact with individual measurement error to affect group-level correlations. Drawing on the three-stage meditational model (see Figure 1), the interaction model segregates salient moderators into the factors that are characteristics of the group, and which have their impact on the amount of error variance extant in the group means, into between-group factor that determines how much of the error variance in group means translates into unreliability in a classical true-score theory sense, and lastly, into inter-variable relationship factor that influences how unreliability, due to error variance, would translate into attenuation in observed correlation.

Group Size

Individual group members' scores may be separated into two samples or two vectors. One vector would contain all the true scores and another all the error scores. Drawing on the basic statistical theory, the bigger the sample, the closer, on average, is the mean of that sample to the mean of the population (i.e., the bigger the sample, the smaller the standard error of the mean). Thus, the bigger the group size, the closer the mean of the vector of the error scores is to the population mean, which (i.e., the population mean), of course, is zero. Thus, the effect of increasing individual measurement error in creating error variance of the group-level variable would be smaller when the group size is large as opposed to when the group size is small. In other words, the extent to which the observed group mean would deviate from the true group mean would diminish as group size increases.

[1] Due to page limitations, the figures were posted online and may be accessed at http://www.nesterkin.com/swdsi2009/.

Number of Items

The understanding of the effect of individual measurement error cannot be divorced from the inclusion of the scale length moderating variable. Constructs are typically assessed using multi-item scales and responses to these items are summed up or averaged by each individual before being further aggregated to the group level. Multi-item scales are used because "the reliability of instrument will increase as a result of adding items that measure the same phenomenon" (Pedhazur & Schmelkin, 1991, p. 101). Thus, by increasing the number of items used in a scale, the measurement error is decreased at each group member's level first, which, consequently, stabilizes the observed group means. That is, the effect of increasing individual measurement error in creating error variance of the group-level variable would be smaller when a number of items composing a scale is large as opposed to when the number of items composing a scale is small.

Group Size and Number of Items

Drawing on the rationale stated in two previous paragraphs, it is reasonable to expect that these two factors; namely, group size and number of items, would interact with each other such that the effect of increasing individual measurement error in creating error variance of the group-level variable would be smaller when the number of items used in a scale is large and, at the same time, the group size is large also, as opposed to when just the group size or when just the number of items is large.

True Between-Group Variability

The second stage of the mediational model depicts the influence of increasing error variance in decreasing the reliability of the group-level variable. According to classical test theory (Pedhazur and Schmelkin, 1991, p. 85), the reliability is a function of true-score and error variances, and the extent to which error variance can undermine the reliability of a variable is determined by the level of true-score variance. Therefore, one would expect true-score variance to be an important moderator of the relationship between error variance and reliability. In the context of groups, true-score variance is true between-group variability that can be computed by taking all group averages (computed assuming a level of measurement error of 0) and then computing the variance of those averages. When the true between-group variability is high one would expect the effect of error variance in attenuating the reliability to be not as severe as compared to when true between-group variability is low. Suppose that a researcher has two samples of 30 groups each and the only thing that is different about these two samples is the true between-group variability of the first sample is 2 and the true between-group variability of the first sample is 1. Suppose, also, that the level of measurement error is the same for every single group, which creates an error variance, of the group-level variable, of 1 for both samples of groups. In the case of the first sample, the reliability would be 0.67 (i.e., 2 [true-score variance] / (2 [true –score variance] + 1 [error variance])); whereas in the case of the second sample the reliability would be 0.5 (i.e., 1 [true-score variance] / (1 [true-score variance] + 1 [error variance])). Despite the fact that in both samples of groups the same level of measurement error produced the same amount of error variance, the findings derived from the first sample would be more robust, because higher true between-group variability offsets the attenuating impact of the error variance.

The third stage of the mediational model depicts the influence of decreasing reliability of aggregated group-level variable in decreasing the observed group-level correlation. According to Pedhazur and Schmelkin (1991, p. 113), the observed correlation between any two variables is a product of existing true correlation (i.e., effect size) between these two variables multiplied by the square root of the product of reliabilities for each of these two variables. Therefore, the extent to which reliability of the group-level variable influences group-level correlation is moderated by the true correlation that exists between these two group-level variables. Suppose that a researcher has two samples of 30 groups each and the only thing that is different about these two samples is true correlation that exists between two group-level variables, which for the first sample is 0.9 and for the second sample is 0.5. Suppose that the level of measurement error for every single group in both of the samples happens to be the same, which creates an error variance of 1 for both samples of groups, which in turned drops the reliability of the aggregated group-level variable, in both samples, to 0.7. However, the observed correlation in the first sample would be 0.75; whereas the observed correlation in the second sample would be 0.41. In other words, for one constant unit change in reliability, from 1 to 0.7, in the first case the true correlation coefficient dropped 0.15, whereas in the second case it dropped 0.09. In essence, and intuitively, the more there is to attenuate (i.e., when the true correlation is high) the more will be attenuated when the reliability drops.

In summary, as individual measurement error increases, it increases the error variance of the aggregated group-level variable. However, the extent to which the error variance is increased is a function of group size and the length of the measurement scale. The increase in the error variance is greatest when the group size is small and the number of items used to assess a construct is one. The increase in the error variance is lowest when the group size is large and the number of items used to assess a construct is large. Subsequently, the increasing error variance attenuates the reliability of the aggregated group-level variable. However, this attenuation in reliability is lowest when true between-group variability is high and highest when the true between-group variability is low. In turn, decreasing reliability of the aggregated group-level variable, due to increasing error variance, due to increasing individual measurement error, attenuates the observed correlation between two group-level variables. However, the attenuation in observed correlation is lowest when the true correlation is low, and the attenuation in observed correlation is highest when the true correlation is high (the entire model is presented in Figure 2).

RESULTS[2]

Stage 1 model results are presented in Figure 3a to 3e. Figure 3a depicts a worst-case scenario, i.e., a scenario when group size is low and number of items is small. Under these conditions the effect of measurement error is most salient in deviating observed group-scores (i.e., group means) from true group-scores, thereby creating the highest level of error variance. When the group size is changed from low (i.e., 2) to high (i.e., 16) (see Figures 3a through 3e), the measurement error still has a salient effect in creating error variance; however, this effect is not as pronounced as when group size is low (see Figure 3a), resulting from a two-way interaction between the measurement error and the group size. It ought to be noted that the moderating effect of group size is increasingly decreasing. That is, in nominal terms, when group size is increased from 2 to 4

[2] The results were obtained using Monte Carlo simulation study. The explanation of the method is omitted due to page limitations.

(see Figures 3a and 3b), the error variance is decreased by 0.23 from about 0.45 to 0.22. However, when group size is increased by additional 2 (see Figure 3c), from 4 to 6, the error variance is decreased by 0.07 from about 0.22 to 0.15.

The moderating role of the number of items variable can be observed in Figures 3a, and 3f through 3i. That is, under the conditions when number of items is large (i.e., 7, see Figure 3i) the effect of measurement error is not nearly as severe in creating error variance as when the number of items is small (i.e., 1, see Figure 3a), resulting from a two-way interaction between measurement error and number of items. Similar to the moderating effect of the group size, the moderating effect of the number of items is increasingly decreasing. That is, in nominal terms, when number of items is increased from 1 to 2 (see Figures 3a and 3f), the error variance is decreased by 0.23 from about 0.45 to 0.22. However, when number of items is increased by additional 1 (see Figure 3g), from 2 to 3, the error variance is decreased by 0.07 from about 0.22 to 0.15. It also appears that increasing number of items by 1 would have about the same moderating effect as increasing group size by 2.

Additionally, the moderating effect of the number of items changes depending on the level of group size. That is, under conditions when group size and number of items are concurrently increased by, say, 2 and 1, respectively (see Figure 3j), from their lowest levels, the effect of measurement error in creating error variance is less severe compared to when just the group size is increased by 2 (see Figure 3b) or when just the number of items is increased by 1 (see Figure 3f), resulting from a three-way interaction between measurement error, group size, and number of items. The same three-way moderating effect can be observed when group size and number of items are concurrently increased to their maximum levels, i.e., 16 and 7, respectively (see Figure 3k). The effect of measurement error in creating error variance is less severe compared to when just the group size is increased to its maximum level (see Figure 3e) or when just the number of items is increased to its maximum level (see Figure 3i).

Insert Figures 4a through 4c about here

Stage 2 model results are presented in Figures 4a through 4c. As expected, the increase in error variance leads to a decrease in the reliability of the group-level variable. However, the nature of the relationship between these two variables changes dramatically, depending on the level of true between-group variability. When true between-group variability (See Figure 4a) is very low, the relationship between error variance and reliability is exponential, such that a slight increase in the error variance leads to a sharp decrease in reliability. The relationship between error variance and reliability becomes linear and less steep at medium and high levels of between-group variability (see Figures 4b and 4c), such that even at the highest levels of error variance, when true between-group variability is high, the reliability still hovers around 0.8 (see Figure 4c), reflecting a strong two-way interaction between error variance and between-group variability.

Insert Figures 5a through 5c about here

Stage 3 model results are presented in Figures 5a through 5c. As expected, a decrease in the reliability of the group-level variable leads to a decrease in observed correlation between two group-level variables. This relationship, however, is strongly influenced by the level of true correlation that exists between two group-level variables, such that changes in reliability have little effect on the observed correlation when the level of true correlation is very low (i.e., 0.1, see Figure 5a). However, when the level of true correlation is very high (i.e., 0.9, see Figure 5b), the relationship between reliability and observed correlation becomes more pronounced, suggesting a strong two-way interaction between reliability and true correlation.

Reflecting on the results in Figures 3, 4, and 5, it is evident that high levels of measurement error bias group-level correlations downward by increasing the error variance of the group-level variable, which, in turn, decreases the group-level variable's reliability, which, finally, attenuates the observed correlation. This process does not take place in isolation and there are several salient contextual factors that influence the effect of measurement error. Specifically, the effect of measurement error in biasing observed correlation is most severe when group size is low, number of items is low, between-group variability is low, and true correlation is high. The effect of measurement error has almost no effect on observed correlation when group size is high, number of items is high, between-group variability is high, and true correlation is low. Additionally, reflecting on stages 1 and 2 results, it is evident that all three moderators – group size, number of items, and true between-group variability – are salient in their potential to offset the attenuating effect of measurement error; however, the most salient of the three is true between-group variability.

To corroborate the above-stated explanation of how and under what conditions measurement error operates in biasing group-level correlations, the relationship between measurement error and observed correlation was examined directly, bypassing the error variance and reliability mediators. As before, this analysis begins with a worst-case scenario, i.e., a scenario when group size, number of items, and true between-group variability are low. Each scenario is represented as an error bar plot, within which each level of true correlation (i.e., 0.1, 0.3, 0.5, 0.7, and 0.9) is represented by its respective line. For each level of measurement error and for each level of true correlation, co-jointly, an average observed correlation and its 95% confidence interval were computed. The results are displayed in Figures 6a through 6h. Because in this study a total of four contextual variables were considered (i.e., group size, number of items, true between-group variability, and true correlation), in the interest of space and time, the interactions are analyzed in broad strokes beginning with the worst-case scenario (see Figure 6a) and then "switching" each contextual variable from worst to best in order to observe the interaction effect and its magnitude.

Insert Figures 6a through 6h about here

Figure 6a represents a base scenario when even relatively low levels of measurement error lead to a substantial attenuation in observed correlations, in addition to rapidly increasing correlation error, which is represented by a 95% confident interval lines whose width increases with each level of measurement error. The base scenario saliently changes (see Figure 6b) when group size is "switched" from low (i.e., 2) to high (i.e., 16) with other factors being kept unchanged. The attenuating effect of measurement error, although still severe, becomes less drastic and correlation error, although still large, diminishes by approximately a factor of 2. A scenario similar to the one in Figure 6b can be observed in Figure 6c when the base, i.e., worst-case scenario (Figure 6a), is changed by "switching" number of items variable from low (i.e., 1) to high (i.e., 7). As in Figure 6b, the measurement error still has a severe, although less drastic, effect, with correlation error diminishing by also about a factor of 2. In Figure 6d, the true between-group variability is "switched" from low to high (i.e., from 0.14 to 1.82) while keeping other factors constant. The attenuating effect of measurement error almost completely disappears for low levels of true correlation (i.e., 0.1 and 0.3) and attenuating effect becomes small for high levels of true correlation. The level of correlation error shrinks significantly especially under conditions when the level measurement error is low to medium.

Figure 6e depicts a scenario when both group size and number of items are "switched" from low to high, i.e., from 2 to 16 and 1 to 7, respectively. Figure 6e, contrasted with Figures 6b and 6c, points to an interaction between group size and number of items, such that the effect of measurement error in creating error variance of the group-level variable is less severe when both group size and number of items are high, compared to a situation when just either one of these moderators is "switched" from low to high. Contrasting Figure 6e with Figure 6d, it is apparent that the moderating effect of true between-group variability, in the context of this study, is stronger than the joint moderating role of the group size and the number of items variables.

Figure 6f depicts a scenario when both true between-group variability and group size are "switched" from low to high, i.e., from 0.14 to 1.82 and 2 to 16, respectively. Contrasted with

Figure 6d, Figure 6f points to an interaction between true between-group variability and group size, such that the effect of measurement error in creating error variance almost completely disappears and the correlation error becomes a factor only for medium to high levels of measurement error. Very similar interaction pattern is observed in Figure 6g when both true between-group variability and number of items are "switched" from low to high.

Lastly, Figure 6h presents a scenario when all three moderators, i.e., group size, number of items, and true between-group variability, are "switched" from low to high, i.e., from 2 to 16, 1 to 7, and 0.14 to 1.82, respectively. In this case the effect of measurement error in attenuating observed correlations disappears entirely with correlation error remaining slightly noticeable for medium to high levels of measurement error.

CONCLUSION

This study contributes to the extant literature in three ways. First, it presents a theoretically built and empirically validated model that depicts how and when individual-level random measurement error operates in attenuating group-level correlations. Second, this study examines four moderator variables (i.e., group size, scale length, true between-group variability, and effect size) and explains how they condition the influence of measurement error. And third, this paper provides actionable guidelines, based on the model presented, to aid group-level researcher in avoiding some of the pitfalls that occur when there is measurement error, or, at the very least, to aid in the estimation of how distorted one's results might be.

This study's findings reveal that individual-level random measurement error is indeed a factor in attenuating group-level correlations and it operates by increasing error variance of the group-level variable. Increasing error variance, in turn, decreases the reliability of the group-level variable, and decreasing reliability, in turn, decreases the observed correlation between group-level variables.

The effect of measurement error in attenuating the group-level correlations is most salient when group size is low, number of items is low, true between-group variability is low, and true correlation between group-level variables is high. Measurement error essentially has no effect on group-level correlations when group size is high, number of items is high, true between-group variability is high, and true correlation between group-level variables is low. Overall, and contrary to some possible theorizing, based on the classical test theory, the results of this study alert the group-level researcher that empirical results of group-level studies are, in fact, to various degrees, measurement error-biased, and the researcher is advised to undertake certain steps, which are discussed in the last section, to lower or to eliminate the bias altogether.

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