The Effects of a Stress-Relieving Program in Hospital Nurses: A Three-Level Analysis

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1 Data Introduction

The dataset is from the Multilevel analysis: Techniques and applications (Hox, J. J., Moerbeek, M., & Schoot, R, 2018), which contains data from a cross-sectional hypothetical study on stress experienced by nurses in hospitals.

In each of 25 hospitals, four wards were selected and randomly assigned to an experimental or control condition, where the intervention included a training program to cope with job-related stress. After the intervention was implemented, a random sample of 10 nurses from each ward completed a survey to test job-related stress level.

Table 1: Description of Variables

Variable	**Description**
hospital	ID number for a hospital (1, ..., 25), a total of 25 hospitals
ward	Ward numbering within a hospital (1, 2, 3, 4), a total of 4 wards from each hospital
wardid	ID number of ward (not used in programming of analyses)
nurse	ID number for a nurse (1, ..., 1000), a total of 1000 nurses (not used in programming)
age	Nurse's age in years
gender	Nurse's gender (0 = male, 1 = female)
experience	Nurse's years of experience working
stress	Outcome variable, a scale from 1 to 7
wardtype	Type of hospital ward ('general care', 'special care')
hospize	Hospital size ('small', 'medium', 'large')
expcon	Intervention indicator variable ('control', 'experiment') administered at Ward

2 Exploratory Data Analysis

The relationship between Nurse's age and Stress can be described as either linear if we assume that the smoothing was too smooth or as bimodal (decreasing through age 40, increasing between age 40 and 52 years, and decreasing after that). I will use a linear relationship between because there are fewer nurses in the older ages, and that could just be an artifact of the data. Given that both lines are simply parallel to each other, there is no moderating effect of intervention on this association.

There may or may not be an association between gender and stress, as on average, stress seems to be very similar between intervention and control groups. Because among males, there is a large overlap in stress, and it is unclear whether there is an intervention effect among females, the visual inspection of the plot does not suggest a moderating effect of intervention on the association between stress and gender.

There appears to be a linear relationship between observed stress and nurse's experience in years. Given that the two trajectories behave in parallel, this does not suggest a moderating effect of intervention on this association.

Stress does not seem to depend on ward type, as if we were to average the control and intervention boxplots within each ward type, they would be approximately the same. Since the intervention effect size seems to be the same within each ward type, therefore, there does not seem to be a moderating effect.

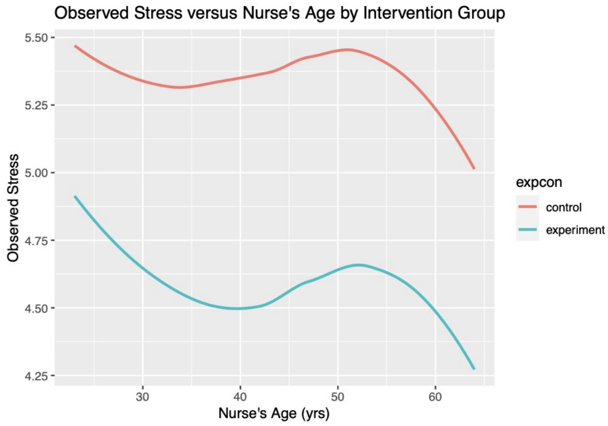

Figure 1: Relationship between Nurse's age and Stress

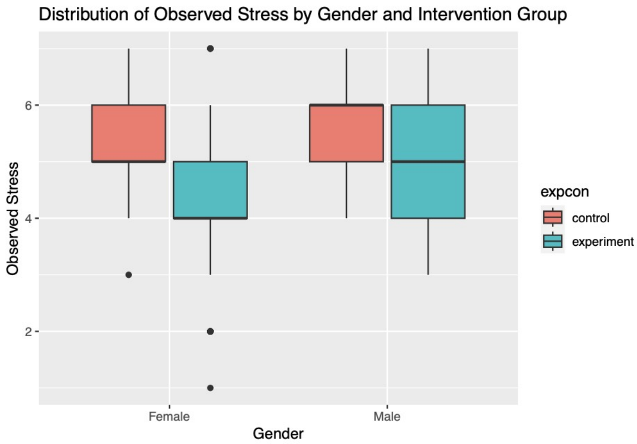

Figure 2: Association between gender and stress

If you average within each hospital size the effect size of intervention, it seems that there is a linear decline in stress across the hospital size. Because the effect size of intervention is different between the hospital sizes, there is a potential moderating effect.

3 Three-level Models

3.1 Model1: Three-level model using only a random intercept at each appropriate level of hierarchy

Level 1 (nurse): $Y_{ijk} = \gamma_{0jk} + \gamma_{1jk}\,\text{Sex}_{ijk} + \gamma_{2jk}\,\text{Cexp}_{ijk} + \gamma_{3jk}\,\text{Cage}_{ijk} + \epsilon_{ijk}$

Level 2 (ward): $\gamma_{0jk} = \gamma_{00k} + b_{0jk} + \gamma_{01k}\text{Nwardtype}_{jk} + \gamma_{02k}\text{Cexpcon}_{ik}$

Level 3 (hospital): $\gamma_{00k} = \beta_{000} + b_{0k} + \beta_{001}\text{Chospsize}_k;$

$$\gamma_{02k} = \beta_{020} + \beta_{021}\text{Chospsize}_k; \gamma_{01k} = \beta_{010}; \gamma_{1jk} = \beta_{100}; \gamma_{2jk} = \beta_{200}; \gamma_{3jk} = \beta_{300}$$

Combined Model: $Y_{ijk} = \beta_{000} + b_{0k} + b_{0jk} + \beta_{001}\text{Chospsize}_k + \beta_{010}\text{Nwardtype}_{ik}$
$+ (\beta_{020} + \beta_{021}\text{Chospsize}_k)\,\text{Cexpcon}_{jk} + \beta_{100}\text{Sex}_{ijk} + \beta_{200}\,\text{Cexp}_{ijk} + \beta_{300}\,\text{Cage}_{ijk} + \epsilon_{ijk}$

The estimated correlation among responses (stress level) within the same ward and the same hospital is 58.42%. The estimated correlation among responses (stress level) from the same hospital regardless of ward type is 26.20%.

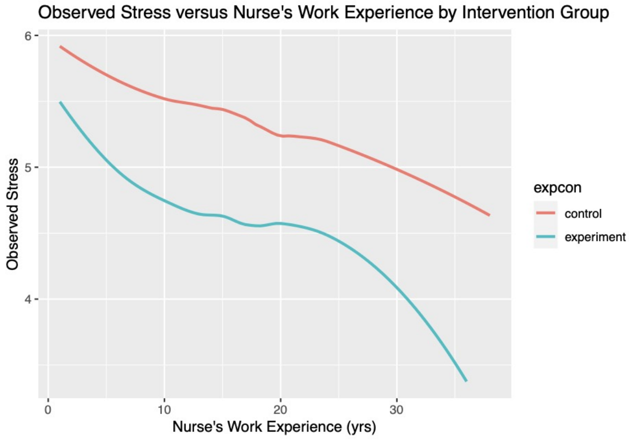

Figure 3: Relationship between nurse's experience and stress

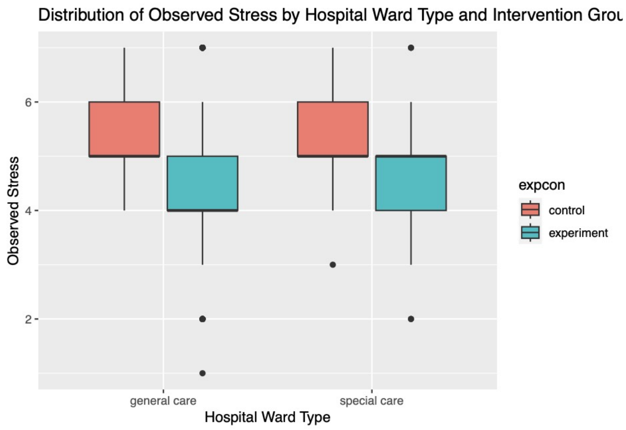

Figure 4: Association between ward type and stress

3.2 Model2: Three-level model adding a random slope for centered intervention indicator variable due to hospital

$$\text{Level 1 (nurse): } Y_{ijk} = \gamma_{0jk} + \gamma_{1jk}\text{Sex}_{ijk} + \gamma_{2jk}\text{Cexp}_{ijk} + \gamma_{3jk}\text{Cage}_{ijk} + \epsilon_{ijk}$$
$$\text{Level 2 (ward): } \gamma_{0jk} = \gamma_{00k} + b_{0jk} + \gamma_{01k}\text{Nwardtype}_{ik} + \gamma_{02k}\ \text{Cexpcon}\ _{ik}$$
$$\text{Level 3 (hospital): } \gamma_{00k} = \beta_{000} + b_{0k} + \beta_{001}\text{Chospsize}_k;$$

$$\gamma_{02k} = \beta_{020} + \beta_{021}\text{Chospsize}_k + b_{02k}; \gamma_{01k} = \beta_{010}; \gamma_{1jk} = \beta_{100}; \gamma_{2jk} = \beta_{200}; \gamma_{3jk} = \beta_{300}$$

$$\text{Combined Model: } Y_{ijk} = \beta_{000} + b_{0k} + b_{0jk} + \beta_{001}\text{Chospsize}_k + \beta_{010}\text{Nwardtype}_{jk} + $$
$$d\left(\beta_{020} + \beta_{021}\text{Chospsize}_k + b_{02k}\right)\text{Cexpcon}_{jk} + \beta_{100}\text{Sex}_{ijk} + \beta_{200}\text{Cexp}_{ijk} + \beta_{300}\text{Cage}_{ijk} + \epsilon_{ijk}$$

The ICC within the same ward, the same hospital, and same condition is 68.86%. The ICC within the same ward and the same hospital is 39.74%. The ICC within the same hospital is 23.81%.

Looking at the estimates of parameters of the G-side and R-side covariance, and their 95% Confidence Intervals in M2, we have:

- Compare the correlation matrices of two models. M2 is similar to M1, since the majority of heterogeneity in stress (response variable) is explained by the correlation among responses from the same ward within a hospital, but it is now composed of an additional source of heterogeneity due to the varying effect sizes of intervention across different hospitals.
- Estimated variance of b_{0k} is 0.1516 and it describes the variability in stress across different hospitals (Level 3 variance component);
- Estimated variance of b_{0jk} is 0.1087 and it describes the variability in stress across different wards within the same hospital (Level 2 variance component);

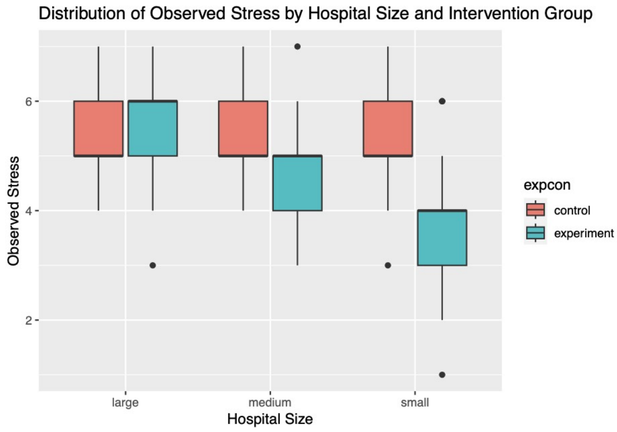

Figure 5: Association between hospital size and stress

- Estimated variance of b_{02k} is 0.1784 describes variability in intervention effects across hospitals (Level 3 variance component);
- Estimated correlation between b_{0k} and b_{02k} is 0.34, which means the larger the deviation of a hospital's mean for nurses' stress from the overall mean of stress averaged across all hospitals, the larger the deviation for that hospital's intervention effect from the overall intervention effect size averaged across all hospitals.
- Estimated residual variance of 0.2166 is the estimated variance of epsilon and it captures the variability of the individual nurse's stress levels around the mean stress level for a specific ward within a hospital.

3.3 Model Comparison

To compare the two models, the only difference between them is in the covariance matrix – therefore, we need to conduct a LRT using REML:

The hypotheses are:

$$\mathrm{H}_0 : \sigma^2_{b_{02k}} = 0$$
$$\mathrm{H}_1 : \sigma^2_{b_{02k}} \neq 0$$

The likelihood ratio test (LRT), implemented via REML, with df=2, G2=8.406 and p=0.0149 (smaller than 0.10), indicates that the addition of the **random effect of intervention across different hospitals** is significantly improving the fit of the model to the data. Hence, we choose model2 as our final model.

3.4 Fixed effects of the final model

- *Intercept*: estimated mean stress for a male nurse working on a general ward of a medium-sized hospital, with average age and average years of experience, is 5.40 points;
- *Age.c*: **for every one year of increase in age, mean stress level significantly increases by 0.02 points;**
- *Gender*: **female nurses reported on average significantly lower stress than male nurses, and that difference is estimated to be 0.45 points;**
- *Experience.C*: **for every one year of increase in work experience, mean stress level significantly decreases by 0.06 points;**
- *Wardtype.n*: while the estimated mean stress in a specialty care ward was on average higher than in the general ward by 0.05 points, **this difference was neither clinically nor statistically significant or meaningful;**
- *Chospsize, Cexpcon,* and *Chospsize*$\times$*Cexpcon* should be interpreted together: as hospital size increased from small to medium to large, the significant reduction in mean stress level due to intervention was significantly diminished/diluted: there was **a significant reduction in mean stress level due to intervention at small hospitals** (an estimated reduction of $\mathrm{Beta6} - \mathrm{Beta7} = -0.499 - 0.998 = -1.5$), **a significant reduction in mean stress level due to intervention in medium-sized hospitals** (an estimated reduction of $\mathrm{Beta6} = -0.499$ points), and a non-significant increase in large-sized hospitals (an estimated increase of $\mathrm{Beta6} + \mathrm{Beta7} = -0.499 + 0.998 = 0.499$), meaning that **intervention did not seem to significantly impact mean stress level among nurses in large hospitals.**

```
## Linear mixed-effects model fit by maximum likelihood
##   Data: nurses
##        AIC      BIC    logLik
##   1701.85 1760.743 -838.9249
##
## Random effects:
##  Formula: ~1 + ward | hospital
##  Structure: General positive-definite, Log-Cholesky parametrization
##             StdDev    Corr
## (Intercept) 0.8884047 (Intr)
## ward        0.2721405 -0.887
## Residual    0.5198284
##
## Fixed effects:  stress ~ age.C + gender + experience.C + wardtype.n + Chospsize *      Cexpcon
##                       Value  Std.Error  DF   t-value p-value
## (Intercept)        5.382961 0.10546040 969  51.04248  0.0000
## age.C              0.021435 0.00241943 969   8.85954  0.0000
## gender            -0.457715 0.03823967 969 -11.96963  0.0000
## experience.C      -0.059380 0.00485302 969 -12.23571  0.0000
## wardtype.n         0.058101 0.06388064 969   0.90952  0.3633
## Chospsize          0.377360 0.12256341  23   3.07890  0.0053
## Cexpcon           -0.580067 0.11589863 969  -5.00495  0.0000
## Chospsize:Cexpcon  0.596068 0.09508083 969   6.26906  0.0000
##  Correlation:
##                   (Intr) age.C  gender expr.C wrdty. Chspsz Cexpcn
## age.C              0.007
## gender            -0.264 -0.010
## experience.C      -0.013 -0.818  0.033
## wardtype.n        -0.476 -0.014 -0.004  0.016
## Chospsize          0.231  0.001  0.005  0.002  0.002
## Cexpcon            0.441  0.012 -0.003 -0.004 -0.805  0.018
## Chospsize:Cexpcon  0.021  0.041  0.006 -0.021  0.013  0.112  0.169
##
## Standardized Within-Group Residuals:
##          Min           Q1          Med           Q3          Max
## -3.557085991 -0.672914337  0.003559349  0.678777749  3.170685039
##
## Number of Observations: 1000
## Number of Groups: 25
```

Figure 6: Summary of model1

4 Random Effects Diagnostic Check

5 Random Effects Diagnostic Check

5.1 Histogram and Q-Qplot for the transformed residuals

The histogram of residuals looks pretty normal, and the Q-Q plot indicates no significant departures from normality.

5.2 Marginal transformed residuals

The distribution of transformed residuals relative to each covariate indicates that the model for the mean response fits the data well and that the functional form for each covariate seems to be appropriate, as there are no systematic trends identified visually: the residuals are approximately 0 on average and their variability is approximately half above and half below the average of 0.

5.3 Histograms and Q-Q plots of the random effects BLUPS

- Random Intercept for Hospital: there do not appear to be fatal departures from normality for the random intercepts for Hospital, and their empirical distribution simply reflects the relatively small number of hospitals in the study (only 25 hospitals).
- Random Treatment Effect across Hospitals: similarly to the distribution of RE for Hospital, this RE suffers from the small sample size of hospitals, and does not appear to have fatal departures from normality (Q-Q plot).
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```
## Linear mixed-effects model fit by maximum likelihood
##   Data: dat
##        AIC      BIC    logLik
##   1576.761 1640.562 -775.3804
##
## Random effects:
##  Formula: ~c.nexpcon | hospital
##  Structure: General positive-definite, Log-Cholesky parametrization
##             StdDev    Corr
## (Intercept) 0.3893819 (Intr)
## c.nexpcon   0.4223545 0.324
##
##  Formula: ~1 | ward %in% hospital
##         (Intercept)  Residual
## StdDev:   0.3297284 0.4654225
##
## Fixed effects:  stress ~ c.age + gender + c.experience + nwardtype + c.nhospsize *      c.nexpcon
##                          Value  Std.Error  DF   t-value p-value
## (Intercept)           5.399837 0.10010103 897  53.94386  0.0000
## c.age                 0.022297 0.00220087 897  10.13113  0.0000
## gender1              -0.454752 0.03497276 897 -13.00303  0.0000
## c.experience         -0.061808 0.00447027 897 -13.82642  0.0000
## nwardtype             0.053134 0.07258371  72   0.73203  0.4665
## c.nhospsize           0.458217 0.12444194  23   3.68218  0.0012
## c.nexpcon            -0.499094 0.11626939  72  -4.29257  0.0001
## c.nhospsize:c.nexpcon  0.998446 0.16120292  72   6.19372  0.0000
##  Correlation:
##                       (Intr) c.age  gendr1 c.xprn nwrdty c.nhsp c.nxpc
## c.age                  0.007
## gender1               -0.254 -0.014
## c.experience          -0.011 -0.817  0.028
## nwardtype             -0.362 -0.011 -0.004  0.013
## c.nhospsize            0.249 -0.001  0.003  0.002  0.000
## c.nexpcon              0.201  0.009 -0.004 -0.003  0.000  0.062
## c.nhospsize:c.nexpcon  0.056  0.015 -0.003 -0.010  0.000  0.223  0.280
##
## Standardized Within-Group Residuals:
##         Min          Q1         Med          Q3         Max
## -2.77549510 -0.69778033  0.01178434  0.64256902  2.81372299
##
## Number of Observations: 1000
## Number of Groups:
##          hospital ward %in% hospital
##                25                100
```

Figure 7: Summary of model2

- Random Intercept for Ward: there do not appear to be fatal departures from normality for the RE for ward; because there were more wards than hospitals, the histogram and the Q-Q plot for this RE looks better for the other two Res, but it's only due to the increased sample size (number of wards is 100).

6 Discussion

- **Conclusion**: This intervention lowered stress among nurses working in small hospitals and to a smaller degree in medium sized hospitals. The intervention did not exhibit an effect in large hospitals.
- Strength:
  - This analysis was able to incorporated all three levels of clustering while additionally controlling for many covariates, both categorical (nurse gender and ward type) and continuous (nurse age and experience in years).
  - Heterogeneity was accounted for in terms of the intervention's effect at various hospitals. This would NOT be possible via any ANOVA type analysis.

```
Approximate 95% confidence intervals

 Fixed effects:
                      lower        est.       upper
(Intercept)       5.20416450  5.39983659  5.59550868
age.C             0.01799518  0.02229732  0.02659947
gender           -0.52311482 -0.45475196 -0.38638910
experience.C     -0.07054606 -0.06180782 -0.05306958
wardtype.n       -0.09097931  0.05313373  0.19724676
Chospsize         0.20182104  0.45821703  0.71461301
Cexpcon          -0.72994385 -0.49909404 -0.26824423
Chospsize:Cexpcon  0.67838226  0.99844641  1.31851056

 Random Effects:
  Level: hospital
                               lower      est.     upper
sd((Intercept))            0.2771991 0.3893819 0.5469652
sd(Cexpcon)                0.2554489 0.4223545 0.6983133
cor((Intercept),Cexpcon) -0.2634529 0.3238953 0.7360486
  Level: ward
                    lower      est.     upper
sd((Intercept)) 0.2605456 0.3297284 0.4172812

 Within-group standard error:
    lower      est.     upper
0.4444111 0.4654225 0.4874272
```

Figure 8: 95% confidence intervals of M2

	Value	Std.Error	DF	t-value	p-value
(Intercept)	5.399858	0.10327271	897	52.28737	0.0000
age.C	0.022300	0.00219598	897	10.15512	0.0000
gender	-0.454716	0.03489625	897	-13.03050	0.0000
experience.C	-0.061804	0.00446073	897	-13.85515	0.0000
wardtype.n	0.053069	0.07304260	72	0.72655	0.4699
Chospsize	0.458206	0.12922692	23	3.54575	0.0017
Cexpcon	-0.498967	0.12074955	72	-4.13225	0.0001
Chospsize:Cexpcon	0.998592	0.16741718	72	5.96469	0.0000

Figure 9: Fixed effects of the final model

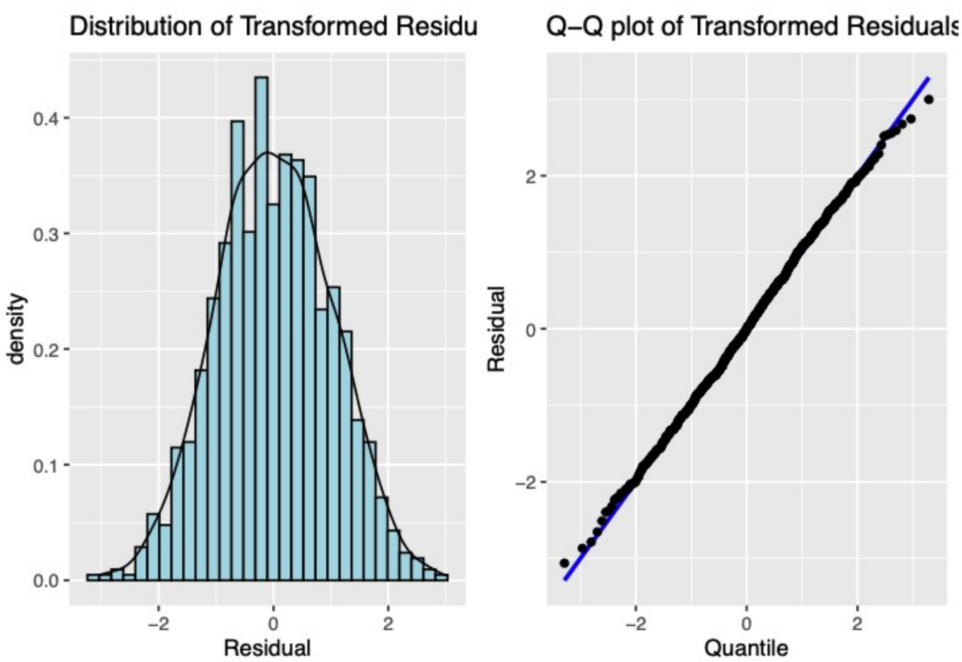

Figure 10: Histogram and Q-Q plot for the transformed residuals

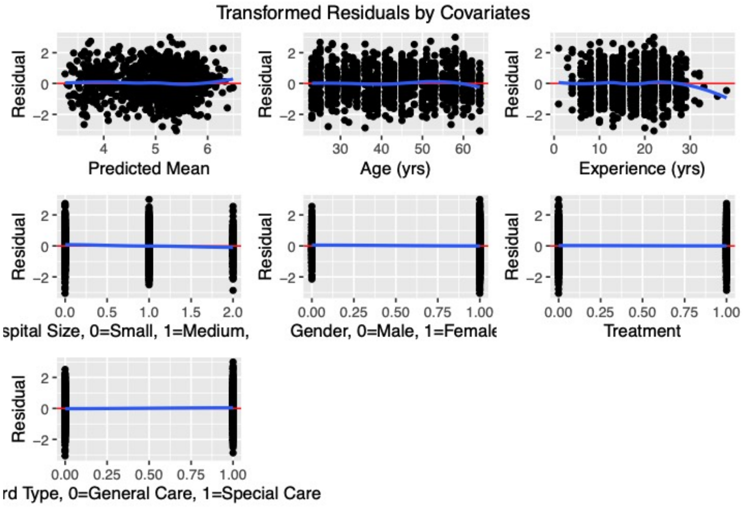

Figure 11: Marginal transformed residuals

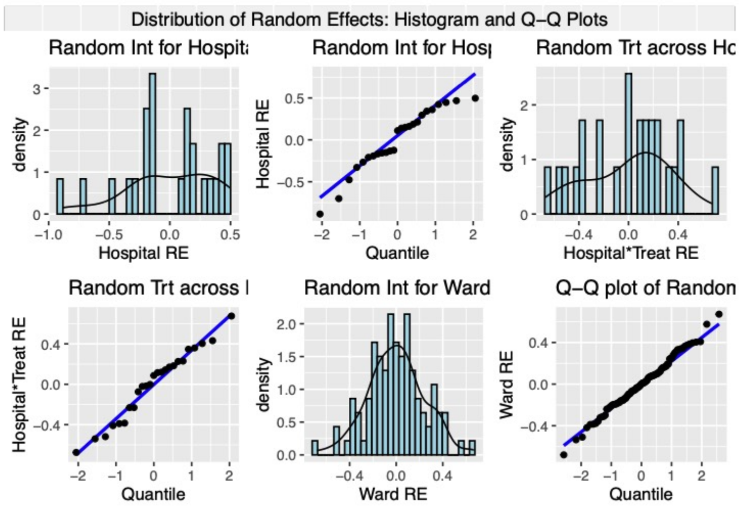

Figure 12: Histograms and Q-Q plots of the random effects BLUPS