The Effect of Cognitive Training on Cognitive Abilities of the Elderly

Introduction

Elderly people express their concerns about declining cognitive ability as this can strongly affect the quality of one's life [Pusswalda et al., 2015]. To find out how cognitive abilities can best be preserved, this research investigates the effects of three cognitive training interventions, namely memory, reasoning and speed training, on cognitive function. The experiment was conducted with the help of 2802 independently living adults of age 65 and older, from six metropolitan areas in the United States. They were divided into four groups. The first group underwent memory training, the second reasoning training, the third speed training and the fourth, the control group, no training. For each participant, the baseline variables, age, gender and education level were recorded. Each participant was observed at three points in time: before, after and one year after treatment. Just before the final observation 60% of the participants received a booster training. Various measures for reasoning, memory and speed abilities were collected, but this paper focuses on the Hopkins Verbal Learning Test (HVLT) score, which assesses verbal learning and memory [Brandt, 1991]. The mean for this variable is 25.42 with a standard deviation of 5.63, a minimum of 0 and a maximum of 36. We aim to answer the following research questions with our analysis:

1. *How do the treatments affect the HVLT score?*
2. *What are the long-term effects of the treatments?*
3. *Does the HVLT score differ for subgroups?*

Methodology

To investigate the research questions, we estimate a model based on equation 1 with $HVLT^2$ as the dependent variable.

$$y_{ijgmklt} = \mu + \beta_i + \alpha_j + \delta_g + \gamma_m + \omega_t + (\beta\omega)_{it} + a_k + e_{ijgmklt} \tag{1}$$

The model includes the factor for training as a fixed effect, β_i, as we wish to investigate the effect of the different types of training on memory for research question one. We can look at the sign of the estimates and use the P-value to determine if the effect is statistically significant. A P-value below 0.05 means that the effects are statistically significant, as the null hypothesis that the effect equals 0 is rejected, at the 5% significance level.

Ahrenfeldt et al. [2018] found differences in cognitive function between gender, hence we include gender as a fixed effect, δ_g. As age impacts cognition [Murman, 2015], age categories are also included as a fixed effect, α_j. Similarly, the level of education might influence cognitive functioning [Lövdén et al., 2020] and is therefore included by the fixed effect γ_m. We further include time as a fixed effect, ω_t, since all levels thereof which are relevant to this study are included. Treating the baseline variables as fixed effects (because the data contains all of their levels or those relevant to the study) enables us to conduct subgroup-specific analyses on their effects. Thus, to answer the third research question, we use the P-values of the estimated effects of the baseline factors to determine if they have a statistically significant positive or negative effect.

We further include a crossed factor between treatment and time to evaluate how the effect of treatment changes over time. The estimate of such a crossed factor between treatment and the annual period, allows us to answer research question two, by using the P-value and looking at whether it is significantly positive or negative. The site is included as a random factor, a_k, as the selected sites are a random draw of all the possible locations and we wish to generalize our results over all of those in the United States. Finally, the subscript l denotes a certain individual (ID). Similarly, the individuals are assumed to be a random draw, so that the results can be generalized.

The model assumes that the random effect of site is normally distributed by $a_k \sim N(0, \sigma_{site})$. As individuals with a relatively high/low baseline score are likely to have a relatively high/low score later in time, there exists correlation between the outcomes at the different points in time. Equations 2 and 3 capture this correlation structure. Equation 2 shows that there are observations at three-time points and equation 3 describes the distribution and covariance matrix for the residuals. The variable ρ_{xy} is the correlation between observations at time x and y. The model is estimated using the Satterthwaite approximation of degrees of freedom and REML estimation.

$$e_{ijgmlk} = (e_{ijgmlk1}, e_{ijgmlk2}, e_{ijgmlk3}) \tag{2}$$

$$e_{ijgmlk} \sim N\left(\begin{pmatrix}0\\0\\0\end{pmatrix}, \begin{pmatrix}\sigma^2_{R,1} & \rho_{12}\sigma_{R,1}\sigma_{R,2} & \rho_{13}\sigma_{R,1}\sigma_{R,3}\\ \rho_{12}\sigma_{R,1}\sigma_{R,2} & \sigma^2_{R,2} & \rho_{23}\sigma_{R,2}\sigma_{R,3}\\ \rho_{13}\sigma_{R,1}\sigma_{R,3} & \rho_{23}\sigma_{R,2}\sigma_{R,3} & \sigma^2_{R,3}\end{pmatrix}\right) \tag{3}$$

Model Validity

We use $HVLT^2$ as our outcome variable because it better adheres to the underlying assumptions of the model than $HVLT$. Figure 1b, in Appendix A, shows the histogram of the residuals. We conceive that the assumption of having normally distributed residuals is quite plausible. This assumption is not necessary for estimating the model, but for constructing confidence intervals and hypothesis tests. However, the mean of the residuals is 4.88, not 0. This deviation is small and deemed close enough to 0, considering the scale of the values. Using $HVLT^2$ as our dependent variable has a detrimental effect on the interpretability, as it does not allow conclusions concerning the magnitude of effects on $HVLT$ but only answers to binary questions about the sign and relative size of estimated effects of factors on it.

Results

Table 1 shows the estimated fixed effects. Memory training has a statistically significant positive effect on the HVLT score relative to the control group. For reasoning and speed training, the P-values exceed 0.05, indicating that we do not reject the hypothesis that their effects are zero. Hence, people who received such training score similarly on $HVLT$ as the control group.

Similarly, the effects of the interaction term between treatment and period were all insignificant, implying that the effect of treatment is not time-dependent.

On average, men score significantly lower than women, as indicated by the statistically significant negative value. The signs for low and medium education levels were significantly negative indicating that those with high education levels scored the highest HVLT scores, on average. The estimated effect of low education was more negative than that of medium education, indicating that low-education individuals scored lowest, on average. Furthermore, as can be deduced from the significant positive effects for individuals with ages 65-69 and 70-74 (of which the effect for ages 65-69 was largest), the younger individuals are, the higher they score on the HVLT test, on average.

Table 2 provides values for the covariance matrix of the residuals and variance component of site. We observe a positive correlation between the scores of one person through time.

Conclusions

In this report, it is established that only memory training has a significantly positive effect on the HVLT score, implying that it benefitted verbal learning and memory. No interaction effects between treatment and time are statistically significant, indicating that over the long term (at least a year) the effect of training does not diminish. The estimated effects of the baseline variables show that, on average, women tend to have a higher HVLT score than men and that people with higher education tend to have higher HVLT scores and vice versa. Finally, older individuals tend to have a lower HVLT score than younger people.

A major limitation of the model is that the outcome variable is $HVLT_2$ makes quantifying the effects difficult as it only allows answers to binary questions regarding $HVLT$. However, our model fits the underlying assumptions of residual normality better, making the hypothesis tests and confidence intervals more reliable. Secondly, the outcome variable is strictly positive, while the residuals are normally distributed around 0. Hence, there is a small probability of the right-hand side of Equation 1 being negative which does not fit data well.

References

Linda Juel Ahrenfeldt, Lasse Lybecker Scheel-Hincke, Søren Kjærgaard, Sören Möller, Kaare Christensen, and Rune Lindahl-Jacobsen. Gender differences in cognitive function and grip strength: a cross-national comparison of four European regions. *European Journal of Public Health*, 29(4):667–674, 12 2018.

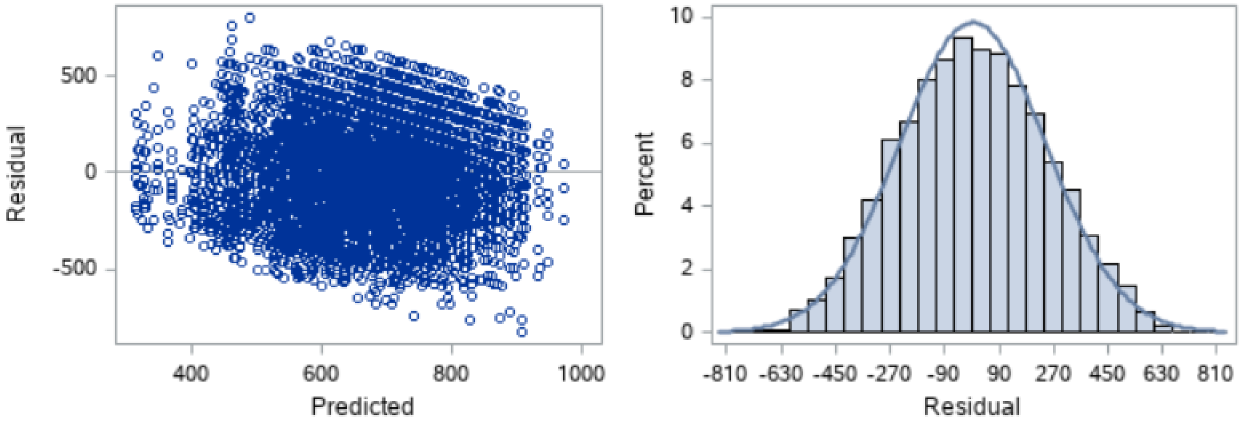
Jason Brandt. The hopkins verbal learning test: Development of a new memory test with six equivalent forms. *Clinical Neuropsychologist*, 5(2):125–142, 1991.

Martin Lövdén, Laura Fratiglioni, M. Maria Glymour, Ulman Lindenberger, and Elliot M. Tucker-Drob. Education and cognitive functioning across the life span. *Psychological Science in the Public Interest*, 21 (1):6–41, 2020.

Daniel Murman. The impact of age on cognition. *Seminars in Hearing*, 36(03):111–121, 2015.

Gisela Pusswalda, Elisa Tropperb, Ilse Kryspin-Exnerb, Doris Mosera, Stefanie Kluga, Eduard Auffa, Peter Dal-Biancoa, and Johann Lehrnera. Health-Related Quality of Life in Patients with Subjective Cognitive Decline and Mild Cognitive Impairment and Its Relation to Activities of Daily Living. *Journal of Alzheimer's Disease*, 47:479–486, 04 2015.

Appendix A: Tables and Figures



(a) (b)

Figure 1: Graphs representing the distribution of the residuals of the provided model: (a) scatter plot representing the predicted values of the conditional residuals and conditional residuals; (b) histogram of the distribution of the conditional residuals.

Table 1: Output of SAS Proc Mixed.

Effect	Factor Level	Estimate	Standard Error	Confidence Interval Lower	Confidence Interval Upper
Intercept		628.61**	18.6198	588.42	668.80
Treatment	Memory	57.15**	11.0836	35.4158	78.8843
	Reasoning	6.4120	11.1404	-15.4336	28.2577
	Speed	3.2660	11.0324	-18.3679	24.8999
	No Training	0	-	-	-
Sex	Boys	-131.56**	9.8430	-150.86	-112.26
	Girls	0	-	-	-
Age	65-69	158.46**	10.1322	138.59	178.32
	70-74	120.24**	9.8903	100.84	139.63
	75+	0	-	-	-
Education	low	-151.72**	10.3047	-171.92	-131.51
	medium	-78.8508**	10.7622	-99.9538	-57.7478
	high	0	-	-	-
Period	Annual	93.5001**	9.3087	75.2457	111.75
	Baseline	104.46**	8.0509	88.6775	120.25
	Post	0	-	-	-
Interaction between effects of Treatment and Period	T1 x Annual	-21.7542	13.1443	-47.5301	4.0217
	T1 $\times$*Post*	0	-	-	-
	T2 $\times$*Annual*	0.3697	13.2414	-25.5965	26.3359
	T2 $\times$*Post*	0	-	-	-
	T3 $\times$*Annual*	-6.0781	13.0948	-31.7568	19.6007
	T3 $\times$*Post*	0	-	-	-
	T4 $\times$*Annual*	0	-	-	-
	T4 $\times$*Baseline*	0	-	-	-
	T4 $\times$*Post*	0	-	-	-

*p-value 0.05,**p-value 0.001

Table 2: Covariance parameters estimates

Covariance Parameter	Estimate	Confidence Interval	
		Lower	Upper
SITE	1178.37	431.92	8934.10
Var(1)	60268**	57080	63732
Var(2)	62965**	59641	66577
Var(3)	55683**	52499	59167
Corr(1,2)	0.6327**	0.6080	0.6573
Corr(1,3)	0.6190**	0.5922	0.6457
Corr(2,3)	0.5930**	0.5656	0.6204
*p-value<0.05,**p-value<0.0001			

Appendix B: SAS code

Please make a folder called "Data" with assignment data in it. Then run the code below.

```
libname  ASSGMNT  "/home/u59376033/Data";
/* Loading the data */
data CognitiveTraining ;
set ASSGMNT.data_assignment ;
run;

proc sql;
        create table squared_outcome as
        select * , (HVLT*HVLT) as squared_HVLT from CognitiveTraining;
QUIT;

PROC MIXED DATA=work.squared_outcome METHOD=reml CL COVTEST plots(maxpoints=none);
CLASS site trt agec sex educ order period;
MODEL squared_HVLT = trt agec sex educ period period*trt/ SOLUTION CL DDFM=SAT residual ;
random site;
repeated order / subject=id type=unr;
RUN;
```