

# A Comparison of the Storage-Only Deficit and Joint Mechanism Deficit Hypotheses of the Verbal Working Memory Storage Capacity Limitation of Children with Developmental Language Disorder

Supplemental Material

*May 1, 2019*

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# 1 Preparation

## 1.1 Load Packages

```
library(tidyverse) # generally handy bits
library(haven)     # work with SPSS files
library(GGally)    # nice pairs plots
library(furniture) # descriptive tables
library(texreg)    # regression tables
library(lmSupport) # compare linear models
library(reghelper) # helper functions for regression
library(rsq)       # R-sq and partial correlations
library(effects)   # marginal effects for plotting
library(pander)    # formating genderal tables
```

## 1.2 Import SPSS Dataset

This dataset was attached to an email from Jim Montgomery 4-30-19 after our conference call with Ron Gillam.

```
data_spss <- haven::read_spss("Master9_Mtch_117x2_v13_with PSs_1-1-18.sav")
```

```
names(data_spss)
```

[1] "id"	"group"	"SLI"
[4] "TD"	"Propensity_Score"	"Subject_Match"
[7] "at_mo_at_test"	"age7y_9y3"	"age9y4_plus"
[10] "age_group"	"sex"	"mom_educ_ColDeg"
[13] "income_less30k"	"leiter_fg_RS"	"leiter_fc_RS"
[16] "leiter_so_RS"	"leiter_rp_RS"	"IQ_Total_RS"
[19] "leiter_comp"	"crevtrec_rs"	"crevtexp_rs"
[22] "celf_cfd_rs"	"celf_rs_rs"	"tnl_total_rec_rs"
[25] "tnl_total_exp_rs"	"tnl_total_rs"	"crevtrec_SS"
[28] "crevtexp_SS"	"celf_cfd_SS"	"celf_rs_SS"
[31] "casl_antonyms_SS"	"casl_antonyms_RS"	"tnl_total_rec_SS"
[34] "tnl_total_exp_SS"	"composite_z_score"	"digitspan"
[37] "dstrialscor"	"Dollaghan_PPC"	"hl_countacctot"
[40] "Wmspan"	"wmtrialsor"	"gor_d"
[43] "gor_Pr_imputd"	"gor_Br"	"as_overall_acc"
[46] "as_SwitchTrials_acc"	"VAR00156"	"svo_acc"
[49] "sr_acc"	"pas_acc"	"or_acc"
[52] "CanonicalAcc"	"NonCanonicalAcc"	"TotSyntaxCompAcc"
[55] "VAR00149"	"zSV0"	"zSR"
[58] "zpas"	"zOR"	"ZCanonicalAcc"
[61] "ZNonCanonicalAcc"	"ZTotSyntaxCompAcc"	"VAR00002"
[64] "Zcasl_antonyms_RS"	"Ztnl_total_rec_rs"	"Ztnl_total_exp_rs"
[67] "Zdigitspan"	"Zdstrialscor"	"ZDollaghan_PPC"
[70] "Zhl_countacctot"	"ZWmspan"	"ZWmtrialsor"
[73] "Zgor_d"	"Zgor_Pr_imputd"	"Zgor_Br"
[76] "Zas_overall_acc"	"Zas_SwitchTrials_acc"	"VAR00169"
[79] "zWMcomp"	"zCAcomp"	"zLTMcomp"

### 1.3 Prepare Dataset

Outcome:

- `wmtrialscor` - Working Memory capacity

Predictors:

- `dstrialscor` - Verbal Short-Term Storage
- `gor_Pr_imputd` - Sustained Attention
- `as_SwitchTrials_acc` - Attention Switching
- `casl_antonyms_RS` - Long-Term Memory
- `group` - Group
  - **SLI** Language Impaired Group, aka DLD Group
  - **TD** Typically Developing Group

```
data_model <- data_spss %>%
  dplyr::mutate(id = factor(id)) %>%
  dplyr::mutate(group = factor(group,
                                levels = c("TD", "SLI"),
                                labels = c("TD", "DLD"))) %>%
  dplyr::mutate_at(vars(wmtrialscor,
                        dstrialscor,
                        gor_Pr_imputd,
                        as_SwitchTrials_acc,
                        casl_antonyms_RS),
                  as.numeric) %>%
  dplyr::select(id,
                group,
                wmtrialscor,
                dstrialscor,
                gor_Pr_imputd,
                as_SwitchTrials_acc,
                casl_antonyms_RS)

head(data_model)
```

```
# A tibble: 6 x 7
  id   group wmtrialscor dstrialscor gor_Pr_imputd as_SwitchTrials~
<fct> <fct>   <dbl>       <dbl>       <dbl>         <dbl>
1 100   DLD         5         10         0.380         0.739
2 102   DLD         7         13         0.929         1
3 104   DLD         8          9         0.786         0.913
4 105   TD          8          8         0.853         0.870
5 106   DLD        10          9         0.903         0.957
6 107   DLD         7          9         0.857         0.818
# ... with 1 more variable: casl_antonyms_RS <dbl>
```

## 2 Exploratory Data Analysis

### 2.1 Descriptive Summary

```
data_model %>%
  dplyr::group_by(group) %>%
  furniture::table1("Verbal Short-Term Storage" = dstrialscor,
                    "Sustained Attention"      = gor_Pr_imputd,
                    "Attention Switching"      = as_SwitchTrials_acc,
                    "Long-Term Memory"         = casl_antonyms_RS,
                    "Verbal Working Memory"    = wmtrialscor,
                    total = TRUE,
                    test = TRUE,
                    caption = "Descriptive Summary of Measures by Group",
                    output = "latex2")
```

Table 1: Descriptive Summary of Measures by Group

	group			P-Value
	Total n = 234	TD n = 117	DLD n = 117	
Verbal Short-Term Storage	9.9 (2.8)	11.1 (3.0)	8.7 (2.0)	<.001
Sustained Attention	0.8 (0.2)	0.8 (0.1)	0.8 (0.2)	0.018
Attention Switching	0.8 (0.1)	0.9 (0.1)	0.8 (0.1)	<.001
Long-Term Memory	27.3 (7.5)	31.4 (6.5)	23.1 (6.1)	<.001
Verbal Working Memory	6.5 (3.5)	8.1 (3.4)	4.8 (2.8)	<.001

## 2.2 Visualization

### 2.2.1 Convert to Long Fromat

```
data_long <- data_model %>%
  tidyr::gather(key = measure,
                value = score,
                -id, -group, -wmtrialscor) %>%
  dplyr::mutate(measure = case_when(measure == "dstrialscor" ~ 1,
                                   measure == "gor_Pr_imputd" ~ 2,
                                   measure == "as_SwitchTrials_acc" ~ 3,
                                   measure == "casl_antonyms_RS" ~ 4)) %>%

  dplyr::mutate(measure = factor(measure,
                                levels = 1:4,
                                labels = c("Verbal\nShort-Term Storage",
                                             "Sustained\nAttention",
                                             "Attention\nSwitching",
                                             "Long-Term\nMemory"))) %>%

  dplyr::arrange(id, measure)

head(data_long, n = 9)
```

```
# A tibble: 9 x 5
  id   group wmtrialscor measure          score
<fct> <fct>    <dbl> <fct>          <dbl>
1 100   DLD        5 "Verbal\nShort-Term Storage" 10
2 100   DLD        5 "Sustained\nAttention"      0.380
3 100   DLD        5 "Attention\nSwitching"      0.739
4 100   DLD        5 "Long-Term\nMemory"        20.6
5 102   DLD        7 "Verbal\nShort-Term Storage" 13
6 102   DLD        7 "Sustained\nAttention"      0.929
7 102   DLD        7 "Attention\nSwitching"      1
8 102   DLD        7 "Long-Term\nMemory"        24.9
9 104   DLD        8 "Verbal\nShort-Term Storage" 9
```

```
data_superlong <- data_model %>%
  tidyr::gather(key = measure,
                value = score,
                -id, -group) %>%
  dplyr::mutate(measure = case_when(measure == "dstrialscor" ~ 1,
                                   measure == "gor_Pr_imputd" ~ 2,
                                   measure == "as_SwitchTrials_acc" ~ 3,
                                   measure == "casl_antonyms_RS" ~ 4,
                                   measure == "wmtrialscor" ~ 5)) %>%

  dplyr::mutate(measure = factor(measure,
                                levels = 1:5,
                                labels = c("Verbal\nShort-Term Storage",
                                             "Sustained\nAttention",
                                             "Attention\nSwitching",
                                             "Long-Term\nMemory",
                                             "Verbal\nWorking Memory"))) %>%

  dplyr::arrange(id, measure)

head(data_superlong, n = 9)
```

```
# A tibble: 9 x 4
  id   group measure          score
<fct> <fct> <fct>          <dbl>
1 100   DLD  "Verbal\nShort-Term Storage" 10
2 100   DLD  "Sustained\nAttention"       0.380
3 100   DLD  "Attention\nSwitching"       0.739
4 100   DLD  "Long-Term\nMemory"         20.6
5 100   DLD  "Verbal\nWorking Memory"      5
6 102   DLD  "Verbal\nShort-Term Storage" 13
7 102   DLD  "Sustained\nAttention"       0.929
8 102   DLD  "Attention\nSwitching"       1
9 102   DLD  "Long-Term\nMemory"         24.9
```

## 2.2.2 Univariate Distributions

```
data_superlong %>%
  ggplot(aes(score,
              fill = group)) +
  geom_histogram(bins = 12) +
  theme_bw() +
  facet_grid(group ~ measure, scale = "free") +
  theme(legend.position = "bottom")
```

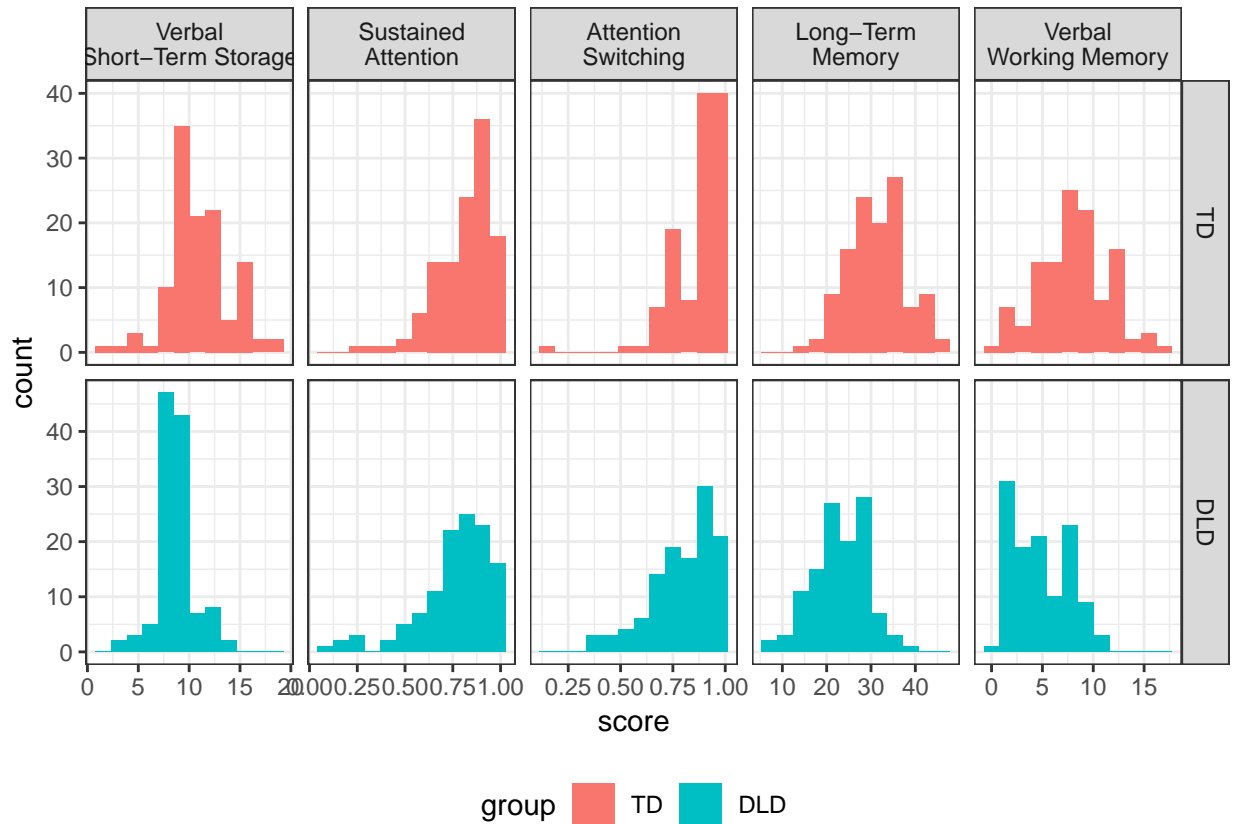


Figure 1: Univariate Distribution of Each Measure, within Each Group, Histograms



```
data_superlong %>%
  ggplot(aes(score,
              fill = group)) +
  geom_density(alpha = .5) +
  theme_bw() +
  facet_wrap(. ~ measure, scale = "free", nrow = 1) +
  theme(legend.position = "bottom")
```

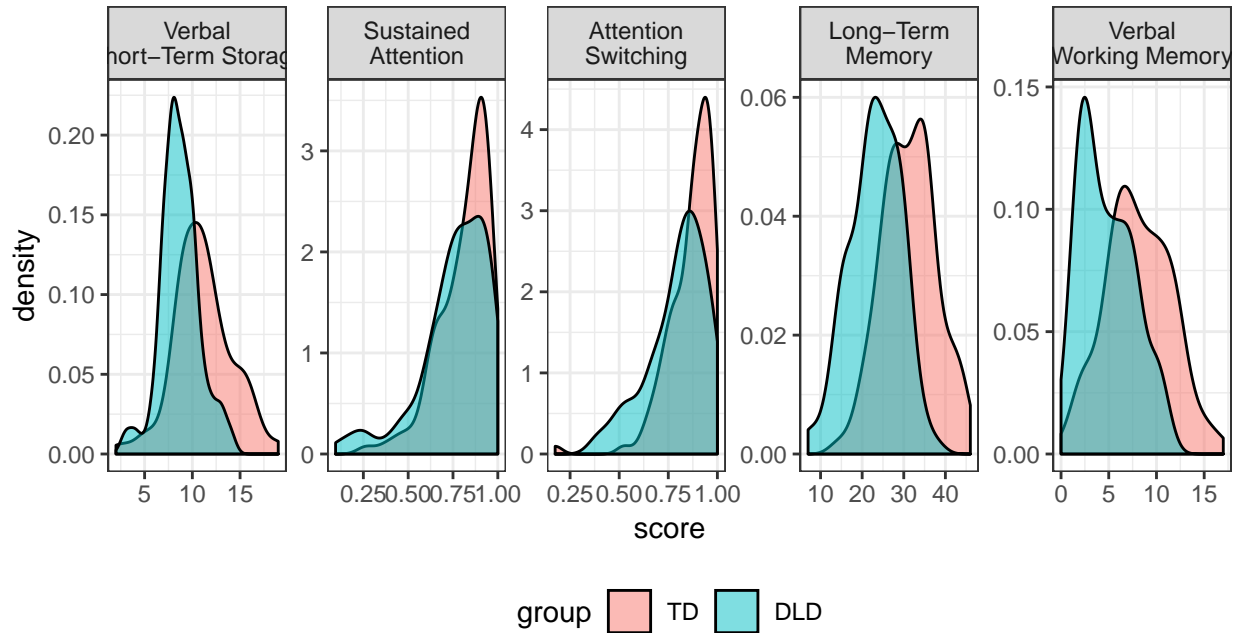


Figure 2: Univariate Distribution of Each Measure, within Each Group, Density Plots

```
data_superlong %>%
  ggplot(aes(y = score,
             x = group,
             fill = group)) +
  geom_boxplot() +
  stat_summary(color = "white") +
  theme_bw() +
  facet_wrap(. ~ measure, scale = "free", nrow = 1) +
  theme(legend.position = "bottom") +
  labs(x = NULL,
       y = NULL)
```

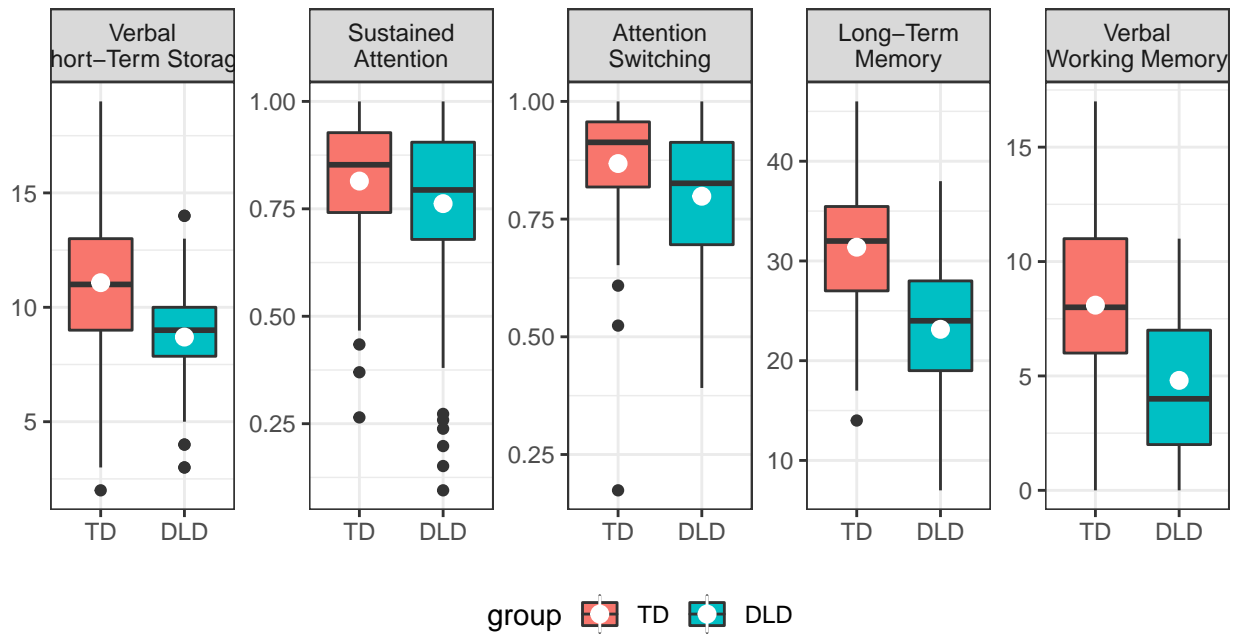


Figure 3: Univariate Distribution of Each Measure, within Each Group, Side-by-Side Boxplots

### 2.2.3 Bivariate Associations

```
data_model %>%  
  data.frame %>%  
  GGally::ggscatmat(columns = 3:7,  
                    color = "group") +  
  theme_bw() +  
  theme(legend.position = "bottom") +  
  labs(x = NULL,  
       y = NULL,  
       color = "Group: ")
```

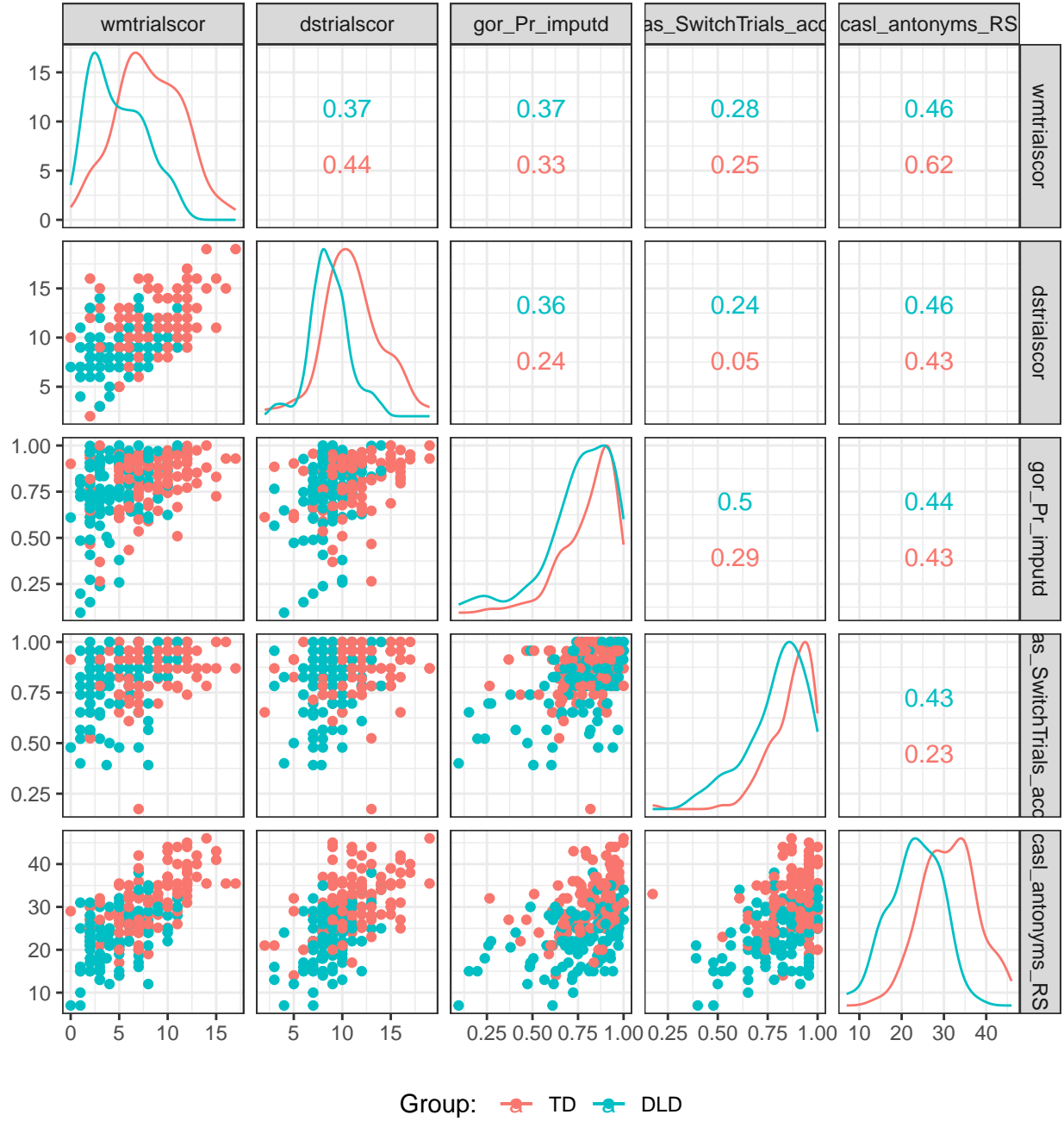


Figure 4: Bivariate Correlation Between All Pairs of Measures, by Group

```
data_long %>%
  ggplot(aes(x = score,
             y = wmttrialscor)) +
  geom_count() +
  geom_smooth(method = "lm",
             se = FALSE) +
  theme_bw() +
  facet_grid(group ~ measure, scale = "free") +
  theme(legend.position = "bottom") +
  labs(x = NULL,
       y = "Working Memory Capacity")
```

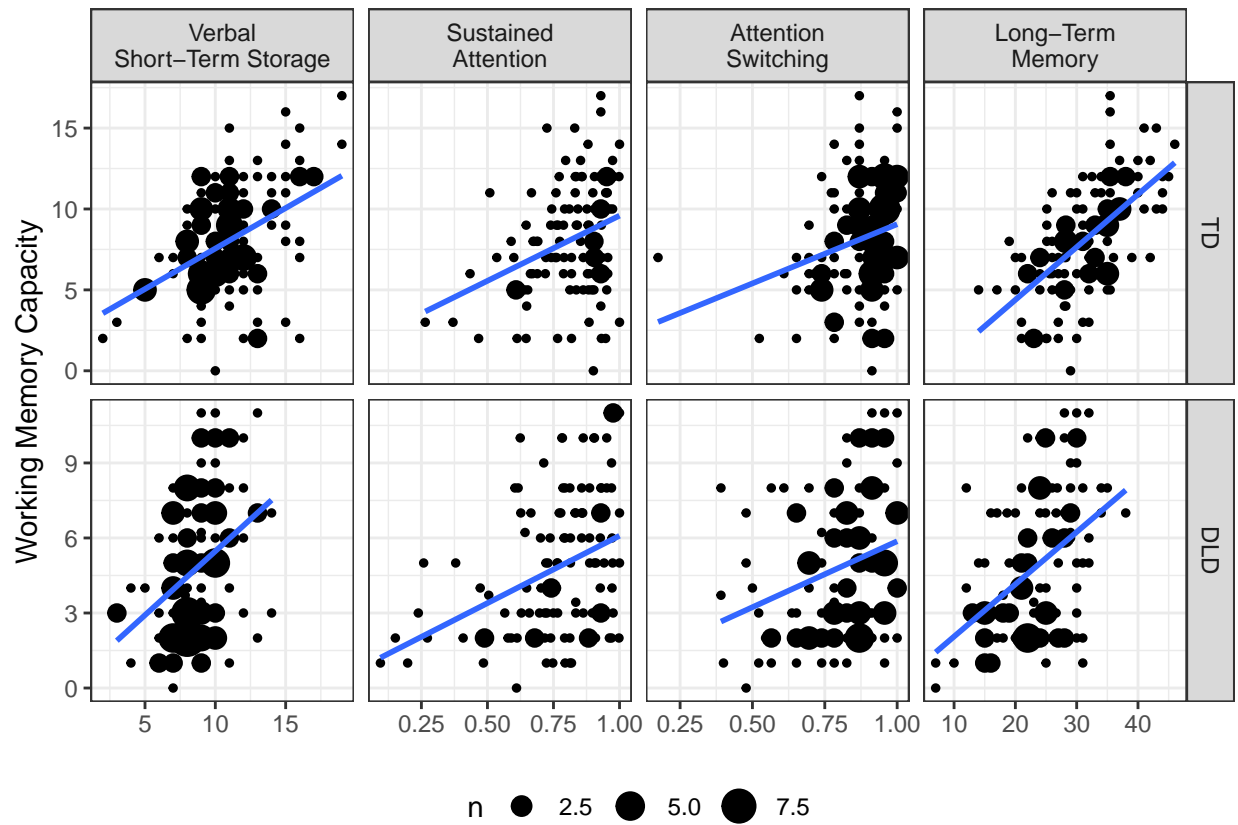


Figure 5: Eight Independent Simple Linear Regression Between Each Predictor and Verbal Working Memory, by Group

```
data_long %>%
  ggplot(aes(x = score,
             y = wmttrialscor,
             color = group,
             fill = group)) +
  geom_smooth(method = "lm") +
  theme_bw() +
  facet_wrap(. ~ measure, scale = "free", nrow = 1) +
  theme(legend.position = "bottom") +
  labs(x = NULL,
       y = "Working Memory Capacity")
```

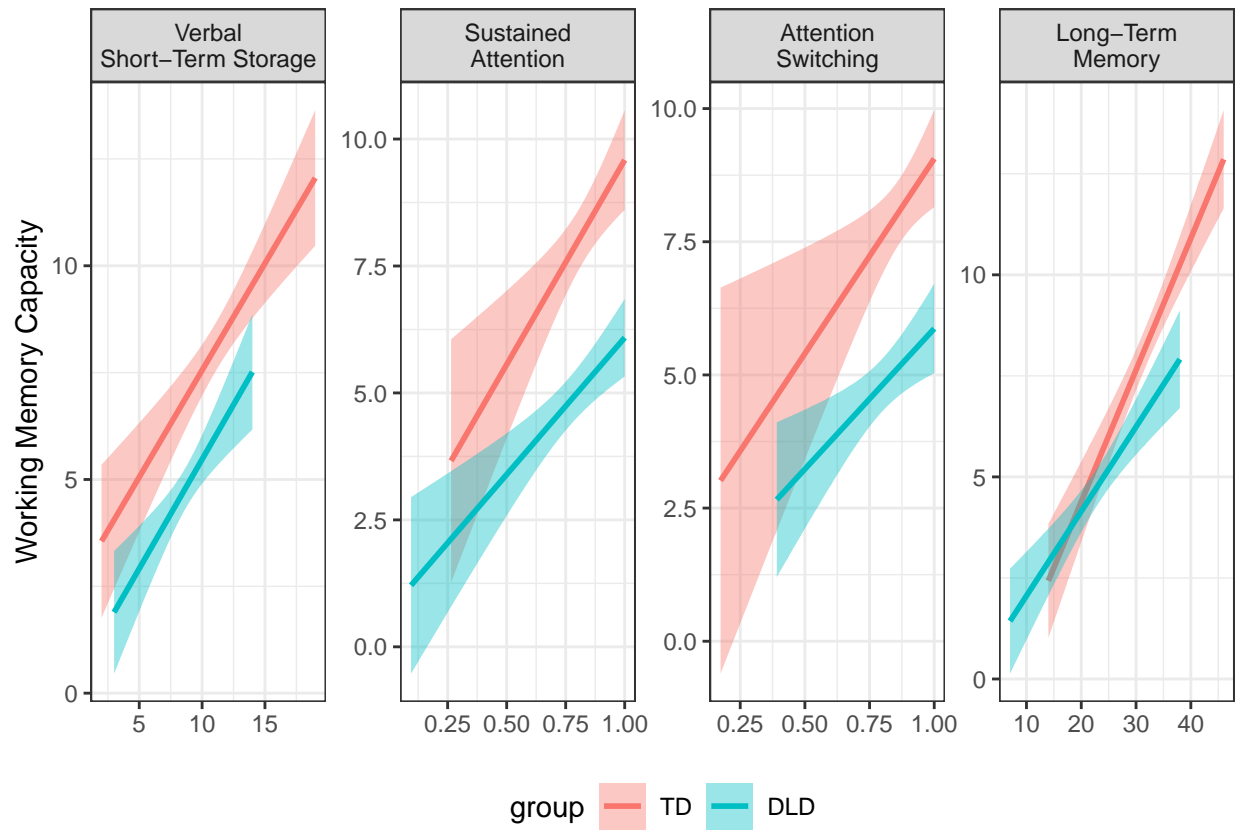


Figure 6: Eight Independent Simple Linear Regressions Between Each Predictor and Verbal Working Memory

## 3 GLM - TD: Typically Developing Group

### 3.1 Fit Nested Models

```
fit_lm_td_0 <- data_model %>%
  dplyr::filter(group == "TD") %>%
  lm(scale(wmtrialscor) ~ 1,
     data = .)

fit_lm_td_1 <- data_model %>%
  dplyr::filter(group == "TD") %>%
  lm(scale(wmtrialscor) ~ scale(dstrialscor),
     data = .)

fit_lm_td_2 <- data_model %>%
  dplyr::filter(group == "TD") %>%
  lm(scale(wmtrialscor) ~ scale(dstrialscor) +
     scale(gor_Pr_imputd),
     data = .)

fit_lm_td_3 <- data_model %>%
  dplyr::filter(group == "TD") %>%
  lm(scale(wmtrialscor) ~ scale(dstrialscor) +
     scale(gor_Pr_imputd) +
     scale(as_SwitchTrials_acc),
     data = .)

fit_lm_td_4 <- data_model %>%
  dplyr::filter(group == "TD") %>%
  lm(scale(wmtrialscor) ~ scale(dstrialscor) +
     scale(gor_Pr_imputd) +
     scale(as_SwitchTrials_acc) +
     scale(casl_antonyms_RS),
     data = .)
```

## 3.2 Parameter Estimates

```
texreg::texreg(list(fit_lm_td_1,
                    fit_lm_td_2,
                    fit_lm_td_3,
                    fit_lm_td_4),
               custom.model.names = c("Storage",
                                      "and SA",
                                      "and AS",
                                      "and LTM"),
               custom.coef.map = list("scale(dstrialscor)"      = "Verbal Short-Term Storage",
                                      "scale(gor_Pr_imputd)"     = "Sustained Attention",
                                      "scale(as_SwitchTrials_acc)" = "Attention Switching",
                                      "scale(casl_antonyms_RS)"  = "Long-Term Memory"),
               bold = 0.05,
               digits = 3,
               single.row = TRUE,
               include.fstatistic = TRUE,
               float.pos = "hb",
               caption.above = TRUE,
               caption = "GLM Parameter Estimates: Typically Developing Group. Estimates are standardized betas.")
```

Table 2: GLM Parameter Estimates: Typically Developing Group. Estimates are standardized betas.

	Storage	and SA	and AS	and LTM
Verbal Short-Term Storage	<b>0.442</b> (0.084)***	<b>0.384</b> (0.084)***	<b>0.388</b> (0.082)***	<b>0.218</b> (0.079)**
Sustained Attention		<b>0.239</b> (0.084)**	<b>0.185</b> (0.086)*	0.037 (0.081)
Attention Switching			<b>0.181</b> (0.083)*	0.121 (0.075)
Long-Term Memory				<b>0.482</b> (0.085)***
R <sup>2</sup>	0.196	0.249	0.279	0.439
Adj. R <sup>2</sup>	0.189	0.236	0.260	0.419
Num. obs.	117	117	117	117
F statistic	27.995	18.937	14.599	21.904
RMSE	0.901	0.874	0.860	0.762

\*\*\*  $p < 0.001$ , \*\*  $p < 0.01$ , \*  $p < 0.05$



### 3.3 Comparisons of Nested Model

```
lmSupport::modelCompare(fit_lm_td_1, fit_lm_td_2)
```

```
SSE (Compact) = 93.28973  
SSE (Augmented) = 87.07268  
Delta R-Squared = 0.05359529  
Partial Eta-Squared (PRE) = 0.06664242  
F(1,114) = 8.139684, p = 0.005144251
```

```
lmSupport::modelCompare(fit_lm_td_2, fit_lm_td_3)
```

```
SSE (Compact) = 87.07268  
SSE (Augmented) = 83.59917  
Delta R-Squared = 0.02994407  
Partial Eta-Squared (PRE) = 0.0398921  
F(1,113) = 4.695105, p = 0.03234825
```

```
lmSupport::modelCompare(fit_lm_td_3, fit_lm_td_4)
```

```
SSE (Compact) = 83.59917  
SSE (Augmented) = 65.08505  
Delta R-Squared = 0.1596045  
Partial Eta-Squared (PRE) = 0.2214629  
F(1,112) = 31.85956, p = 1.267204e-07
```

### 3.4 Partial Correlations

```
rsq::pcor(fit_lm_td_1, fit_lm_td_0)$partial.cor
```

```
[1] 0.4424682
```

```
rsq::pcor(fit_lm_td_2, fit_lm_td_1)$partial.cor
```

```
[1] 0.2581519
```

```
rsq::pcor(fit_lm_td_3, fit_lm_td_2)$partial.cor
```

```
[1] 0.1997301
```

```
rsq::pcor(fit_lm_td_4, fit_lm_td_3)$partial.cor
```

```
[1] 0.4705985
```

## 4 GLM - DLD: Developmental Language Disorder Group

### 4.1 Fit Nested Models

```
fit_lm_dld_0 <- data_model %>%  
  dplyr::filter(group == "DLD") %>%  
  lm(scale(wmtrialscor) ~ 1,  
     data = .)  
  
fit_lm_dld_1 <- data_model %>%  
  dplyr::filter(group == "DLD") %>%  
  lm(scale(wmtrialscor) ~ scale(dstrialscor),  
     data = .)  
  
fit_lm_dld_2 <- data_model %>%  
  dplyr::filter(group == "DLD") %>%  
  lm(scale(wmtrialscor) ~ scale(dstrialscor) +  
                                scale(gor_Pr_imputd),  
     data = .)  
  
fit_lm_dld_3 <- data_model %>%  
  dplyr::filter(group == "DLD") %>%  
  lm(scale(wmtrialscor) ~ scale(dstrialscor) +  
                                scale(gor_Pr_imputd) +  
                                scale(as_SwitchTrials_acc),  
     data = .)  
  
fit_lm_dld_4 <- data_model %>%  
  dplyr::filter(group == "DLD") %>%  
  lm(scale(wmtrialscor) ~ scale(dstrialscor) +  
                                scale(gor_Pr_imputd) +  
                                scale(as_SwitchTrials_acc) +  
                                scale(casl_antonyms_RS),  
     data = .)
```

## 4.2 Parameter Estimates

```
texreg::texreg(list(fit_lm_dld_1,
                    fit_lm_dld_2,
                    fit_lm_dld_3,
                    fit_lm_dld_4),
               custom.model.names = c("Storage",
                                      "and SA",
                                      "and AS",
                                      "and LTM"),
               custom.coef.map = list("scale(dstrialscor)"      = "Verbal Short-Term Storage",
                                      "scale(gor_Pr_imputd)"    = "Sustained Attention",
                                      "scale(as_SwitchTrials_acc)" = "Attention Switching",
                                      "scale(casl_antonyms_RS)"  = "Long-Term Memory"),
               bold = 0.05,
               digits = 3,
               single.row = TRUE,
               include.fstatistic = TRUE,
               float.pos = "hb",
               caption.above = TRUE,
               caption = "GLM Parameter Estimates: Developmental Language Disorder Group. Estimates are
```

Table 3: GLM Parameter Estimates: Developmental Language Disorder Group. Estimates are standardized betas.

	Storage	and SA	and AS	and LTM
Verbal Short-Term Storage	<b>0.370</b> (0.087)***	<b>0.272</b> (0.090)**	<b>0.265</b> (0.090)**	0.169 (0.093)
Sustained Attention		<b>0.272</b> (0.090)**	<b>0.222</b> (0.101)*	0.164 (0.100)
Attention Switching			0.104 (0.097)	0.030 (0.097)
Long-Term Memory				<b>0.293</b> (0.100)**
R <sup>2</sup>	0.137	0.201	0.209	0.265
Adj. R <sup>2</sup>	0.129	0.187	0.188	0.239
Num. obs.	117	117	117	117
F statistic	18.191	14.357	9.966	10.097
RMSE	0.933	0.902	0.901	0.872

\*\*\* $p < 0.001$ , \*\* $p < 0.01$ , \* $p < 0.05$

### 4.3 Comparisons of Nested Model

```
lmSupport::modelCompare(fit_lm_dld_1, fit_lm_dld_2)
```

```
SSE (Compact) = 100.1571  
SSE (Augmented) = 92.66122  
Delta R-Squared = 0.0646201  
Partial Eta-Squared (PRE) = 0.0748417  
F(1,114) = 9.222156, p = 0.002963913
```

```
lmSupport::modelCompare(fit_lm_dld_2, fit_lm_dld_3)
```

```
SSE (Compact) = 92.66122  
SSE (Augmented) = 91.73044  
Delta R-Squared = 0.008023942  
Partial Eta-Squared (PRE) = 0.01004495  
F(1,113) = 1.146597, p = 0.2865445
```

```
lmSupport::modelCompare(fit_lm_dld_3, fit_lm_dld_4)
```

```
SSE (Compact) = 91.73044  
SSE (Augmented) = 85.25605  
Delta R-Squared = 0.05581368  
Partial Eta-Squared (PRE) = 0.07058058  
F(1,112) = 8.505336, p = 0.00427874
```

### 4.4 Partial Correlations

```
rsq::pcor(fit_lm_dld_1, fit_lm_dld_0)$partial.cor
```

```
[1] 0.3695623
```

```
rsq::pcor(fit_lm_dld_2, fit_lm_dld_1)$partial.cor
```

```
[1] 0.2735721
```

```
rsq::pcor(fit_lm_dld_3, fit_lm_dld_2)$partial.cor
```

```
[1] 0.1002245
```

```
rsq::pcor(fit_lm_dld_4, fit_lm_dld_3)$partial.cor
```

```
[1] 0.2656701
```

## 5 GLM - Full Sample

### 5.1 Fit Nested Models - a single two-way interaction

```
fit_lm_all_main <- data_model %>%
  lm(wmtrialscor ~ dstrialscor +
      gor_Pr_imputd +
      as_SwitchTrials_acc +
      casl_antonyms_RS +
      group,
      data = .)

fit_lm_all_1 <- data_model %>%
  lm(wmtrialscor ~ dstrialscor +
      gor_Pr_imputd +
      as_SwitchTrials_acc +
      casl_antonyms_RS +
      dstrialscor*group,
      data = .)

fit_lm_all_2 <- data_model %>%
  lm(wmtrialscor ~ dstrialscor +
      gor_Pr_imputd +
      as_SwitchTrials_acc +
      casl_antonyms_RS +
      gor_Pr_imputd*group,
      data = .)

fit_lm_all_3 <- data_model %>%
  lm(wmtrialscor ~ dstrialscor +
      gor_Pr_imputd +
      as_SwitchTrials_acc +
      casl_antonyms_RS +
      as_SwitchTrials_acc*group,
      data = .)

fit_lm_all_4 <- data_model %>%
  lm(wmtrialscor ~ dstrialscor +
      gor_Pr_imputd +
      as_SwitchTrials_acc +
      casl_antonyms_RS +
      casl_antonyms_RS*group,
      data = .)

fit_lm_all_14 <- data_model %>%
  lm(wmtrialscor ~ dstrialscor +
      gor_Pr_imputd +
      as_SwitchTrials_acc +
      casl_antonyms_RS +
      dstrialscor*group +
      casl_antonyms_RS*group,
      data = .)
```

```

fit_lm_all_24 <- data_model %>%
  lm(wmtrialscor ~ dstrialscor +
      gor_Pr_imputd +
      as_SwitchTrials_acc +
      casl_antonyms_RS +
      gor_Pr_imputd*group +
      casl_antonyms_RS*group,
    data = .)

fit_lm_all_34 <- data_model %>%
  lm(wmtrialscor ~ dstrialscor +
      gor_Pr_imputd +
      as_SwitchTrials_acc +
      casl_antonyms_RS +
      as_SwitchTrials_acc*group +
      casl_antonyms_RS*group,
    data = .)

```

## 5.2 Parameter Estimates

```
texreg::texreg(list(fit_lm_all_1,
                    fit_lm_all_2,
                    fit_lm_all_3,
                    fit_lm_all_4),
               custom.model.names = c("Storage",
                                      "or SA",
                                      "or AS",
                                      "or LTM"),
               custom.coef.map = list("dstrialscor"           = "Verbal Short Term Storage",
                                      "gor_Pr_imputd"         = "Sustained Attention (SA)",
                                      "as_SwitchTrials_acc"   = "Attention Switching (AS)",
                                      "casl_antonyms_RS"      = "Long Term Memory (LTM)",
                                      "groupDLD"             = "DLD group",
                                      "dstrialscor:groupDLD"  = "DLD x Storage",
                                      "gor_Pr_imputd:groupDLD" = "DLD x SA",
                                      "as_SwitchTrials_acc:groupDLD" = "DLD x AS",
                                      "casl_antonyms_RS:groupDLD" = "DLD x LTM"),
               groups = list("Main Effects" = 1:5,
                             "Interactions with Group" = 6:9),
               bold = 0.05,
               digits = 3,
               single.row = TRUE,
               include.fstatistic = TRUE,
               float.pos = "hb",
               caption.above = TRUE,
               caption = "GLM Parameter Estimates: Include a Single Two-way Interction with Group, Estimates are unstandardized betas.")
```

Table 4: GLM Parameter Estimates: Include a Single Two-way Interction with Group, Estimates are unstandardized betas.

	Storage	or SA	or AS	or LTM
Main Effects				
Verbal Short Term Storage	<b>0.292</b> (0.083)***	<b>0.251</b> (0.073)***	<b>0.254</b> (0.072)***	<b>0.240</b> (0.072)**
Sustained Attention (SA)	1.677 (1.178)	2.468 (1.794)	1.768 (1.175)	1.703 (1.161)
Attention Switching (AS)	1.608 (1.403)	1.612 (1.410)	3.881 (2.034)	1.924 (1.397)
Long Term Memory (LTM)	<b>0.198</b> (0.032)***	<b>0.196</b> (0.032)***	<b>0.198</b> (0.032)***	<b>0.254</b> (0.040)***
DLD group	0.482 (1.417)	0.246 (1.704)	2.588 (2.197)	2.488 (1.488)
Interactions with Group				
DLD x Storage	-0.143 (0.143)			
DLD x SA		-1.421 (2.097)		
DLD x AS			-4.108 (2.561)	
DLD x LTM				<b>-0.125</b> (0.053)*
R <sup>2</sup>	0.494	0.493	0.498	0.504
Adj. R <sup>2</sup>	0.481	0.480	0.485	0.491
Num. obs.	234	234	234	234
F statistic	37.010	36.832	37.526	38.492
RMSE	2.539	2.542	2.530	2.514

\*\*\* $p < 0.001$ , \*\* $p < 0.01$ , \* $p < 0.05$

```

texreg::texreg(list(fit_lm_all_4,
                    fit_lm_all_14,
                    fit_lm_all_24,
                    fit_lm_all_34),
               custom.model.names = c("only LTM",
                                      "with Storage",
                                      "with SA",
                                      "with AS"),
               custom.coef.map = list("dstrialscor"           = "Verbal Short Term Storage",
                                      "gor_Pr_imputd"         = "Sustained Attention (SA)",
                                      "as_SwitchTrials_acc"    = "Attention Switching (AS)",
                                      "casl_antonyms_RS"       = "Long Term Memory (LTM)",
                                      "groupDLD"              = "DLD group",
                                      "dstrialscor:groupDLD"    = "DLD x Storage",
                                      "gor_Pr_imputd:groupDLD"  = "DLD x SA",
                                      "as_SwitchTrials_acc:groupDLD" = "DLD x AS",
                                      "casl_antonyms_RS:groupDLD" = "DLD x LTM"),
               groups = list("Main Effects" = 1:5,
                             "Interactions with Group" = 6:9),
               bold = 0.05,
               digits = 3,
               single.row = TRUE,
               include.fstatistic = TRUE,
               float.pos = "hb",
               caption.above = TRUE,
               caption = "GLM Parameter Estimates: Include a Second Two-way Interction with Group. Estim

```

Table 5: GLM Parameter Estimates: Include a Second Two-way Interction with Group. Estimates are unstandardized betas.

	only LTM	with Storage	with SA	with AS
Main Effects				
Verbal Short Term Storage	<b>0.240</b> (0.072)**	<b>0.240</b> (0.086)**	<b>0.240</b> (0.072)**	<b>0.243</b> (0.072)***
Sustained Attention (SA)	1.703 (1.161)	1.702 (1.169)	1.220 (1.861)	1.812 (1.168)
Attention Switching (AS)	1.924 (1.397)	1.924 (1.401)	1.895 (1.403)	3.266 (2.047)
Long Term Memory (LTM)	<b>0.254</b> (0.040)***	<b>0.254</b> (0.041)***	<b>0.258</b> (0.042)***	<b>0.246</b> (0.041)***
DLD group	2.488 (1.488)	2.482 (1.695)	2.108 (1.878)	4.082 (2.318)
Interactions with Group				
DLD x Storage		0.001 (0.157)		
DLD x SA			0.762 (2.290)	
DLD x AS				-2.416 (2.693)
DLD x LTM	<b>-0.125</b> (0.053)*	<b>-0.125</b> (0.059)*	<b>-0.133</b> (0.059)*	-0.109 (0.056)
R <sup>2</sup>	0.504	0.504	0.505	0.506
Adj. R <sup>2</sup>	0.491	0.489	0.489	0.491
Num. obs.	234	234	234	234
F statistic	38.492	32.848	32.880	33.080
RMSE	2.514	2.520	2.519	2.515

\*\*\* $p < 0.001$ , \*\* $p < 0.01$ , \* $p < 0.05$

The three-way was not significant.



### 5.2.1 Simple Slopes

```
simple_slopes(fit_lm_all_4,
  levels = list(group = c("TD", "DLD", 'sstest'),
    casl_antonyms_RS = c(mean(data_model$casl_antonyms_RS), 'sstest')))
```

	casl_antonyms_RS	group	Test	Estimate	Std. Error	t value	df	Pr(> t )
1	sstest	TD		0.2535	0.0397	6.3836	227	9.635e-10
2	sstest	DLD		0.1285	0.0433	2.9697	227	0.003301
3	27.2630341880342	sstest		-0.9209	0.4038	-2.2808	227	0.023488

Sig.

1	***
2	**
3	*

### 5.3 Interpretation

```
summary(fit_lm_all_4)
```

Call:

```
lm(formula = wmtrialscor ~ dstrialscor + gor_Pr_imputd + as_SwitchTrials_acc +
  casl_antonyms_RS + casl_antonyms_RS * group, data = .)
```

Residuals:

	Min	1Q	Median	3Q	Max
	-7.4659	-1.6399	0.1598	1.7384	5.7707

Coefficients:

	Estimate	Std. Error	t value	Pr(> t )
(Intercept)	-5.57927	1.56355	-3.568	0.000438 ***
dstrialscor	0.24011	0.07219	3.326	0.001027 **
gor_Pr_imputd	1.70287	1.16145	1.466	0.143990
as_SwitchTrials_acc	1.92447	1.39745	1.377	0.169829
casl_antonyms_RS	0.25354	0.03972	6.384	9.63e-10 ***
groupDLD	2.48754	1.48789	1.672	0.095931 .
casl_antonyms_RS:groupDLD	-0.12502	0.05324	-2.348	0.019713 *

---

Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 2.514 on 227 degrees of freedom

Multiple R-squared: 0.5043, Adjusted R-squared: 0.4912

F-statistic: 38.49 on 6 and 227 DF, p-value: < 2.2e-16

- In the TD group, for each point higher children are on LTM (holding all other covariates constant) there mean vWM is 0.25 higher.
- Conversely in the DLD group, a similar point higher in LTM is associated with only 0.13 higher on vWM.
- The difference in slopes/associations is statistically significant,  $\beta_{interaction} = -0.125$ ,  $p = .020$ .

### 5.3.1 Visualization

```
data_model %>%
  dplyr::group_by(group) %>%
  dplyr::summarise(min = min(casl_antonyms_RS),
                   mean = mean(casl_antonyms_RS),
                   max = max(casl_antonyms_RS)) %>%
  pander::pander(caption = "Extremes of Long Term Memory Scores, by Group")
```

Table 6: Extremes of Long Term Memory Scores, by Group

group	min	mean	max
TD	14	31.38	46
DLD	7	23.15	38

```
effects::Effect(focal.predictors = c("group", "casl_antonyms_RS"),
               mod = fit_lm_all_4,
               xlevels = list(casl_antonyms_RS = seq(from = 7,
                                                       to = 46,
                                                       by = 1))) %>%

data.frame() %>%
dplyr::filter((group == "TD" & 14 <= casl_antonyms_RS & casl_antonyms_RS <= 46) |
              (group == "DLD" & 7 <= casl_antonyms_RS & casl_antonyms_RS <= 38)) %>%
ggplot(aes(x = casl_antonyms_RS,
           y = fit,
           linetype = group %>% fct_rev(),
           fill = group %>% fct_rev())) +
geom_ribbon(aes(ymin = lower,
               ymax = upper),
           alpha = .25) +
geom_line() +
theme_bw() +
scale_linetype_manual(values = c("solid", "longdash")) +
scale_fill_manual(values = c("gray60", "gray30")) +
theme(legend.background = element_rect(color = "black"),
      legend.position = c(0, 1),
      legend.justification = c(-0.1, 1.1),
      legend.key.width = unit(1.5, "cm")) +
labs(x = "Long Term Memory (LTM)",
     y = "Verbal Working Memory (vWM)",
     fill = "Group: ",
     linetype = "Group: ")

ggsave(filename = "DLD_interaction_plot_SS_5-1-19.png",
       height = 4,
       width = 6,
       units = "in")
```

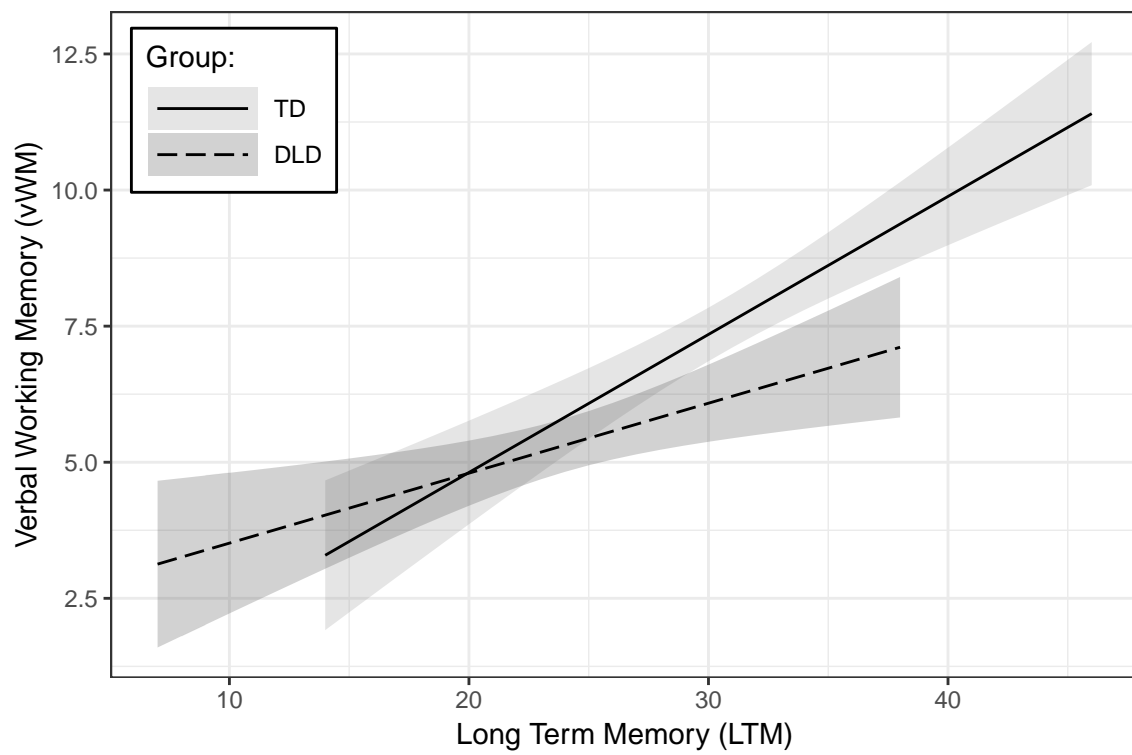


Figure 7: GLM Interaction Plot. Error bands display 95 percent confidence interval for the mean.