

Adults show initial advantages over children in learning difficult non-native speech sounds

Supplementary Materials

1 Relationships between age and non-native learning

1.1 Pre-training sensitivity

Age positively predicts pre-training sensitivity to the contrast.

```
model0_discrim <- lm(dprime ~ Age, data =  
  discrim_trained_talker[discrim_trained_talker$Time  
  == "discrim1",])
```

Table 1: Linear regression model for baseline (pretest) discrimination performance with age as a predictor.

	Estimate	Std. Error	t value	p value
(Intercept)	-0.20	0.21	-0.98	0.33
Age	0.03	0.01	4.62	0.00

1.2 Learning and retention

To test whether participants learned to identify and discriminate the sounds at above-chance levels, we fit several intercept-only models for the immediate posttests and next-day posttests. All intercepts were significantly greater than zero, indicating that participants learned and retained above chance.

1.2.1 Participants identified sounds above chance immediately after training.

```
model0_id <- glmer(correctRC ~ 1 + (1|subject_nr), data = ID_trained_talker[ID_trained_talker$block == "ID_test",], family='binomial')
```

Table 2: Intercept only mixed effects logistic regression model with the immediate identification posttest as dependent variable.

	Estimate	Std. Error	z value	p value
(Intercept)	1.87	0.19	10.07	0.00

1.2.2 Children identified sounds above chance immediately after training.

```
model0_id_children <- glmer(correctRC ~ 1 + (1|subject_nr), data = ID_trained_talker[ID_trained_talker$block == "ID_test" & ID_trained_talker$Group == "Children",], family='binomial')
```

Table 3: Intercept only mixed effects logistic regression model with the immediate identification posttest as dependent variable. Child data only.

	Estimate	Std. Error	z value	Pr(> z)
(Intercept)	1.24	0.17	7.31	0.00

1.2.3 Adults identified sounds above chance immediately after training.

```
model0_id_adults <- glmer(correctRC ~ 1 + (1|subject_nr), data = ID_trained_talker[ID_trained_talker$block == "ID_test" & ID_trained_talker$Group == "Adults",], family='binomial')
```

Table 4: Intercept only mixed effects logistic regression model with the immediate identification posttest as dependent variable. Adult data only.

	Estimate	Std. Error	z value	p value
(Intercept)	2.55	0.31	8.32	0.00

1.2.4 Participants discriminated sounds above chance immediately after training.

```
model00a_discrim <- lm(dprime ~ 1, data =
  discrim_trained_talker[discrim_trained_talker$Time
  == "discrim2",])
```

Table 5: Intercept only linear regression model with the discrimination immediate posttest as the dependent variable.

	Estimate	Std. Error	t value	p value
(Intercept)	1.12	0.11	10.19	0.00

1.2.5 Children discriminated sounds above chance immediately after training.

```
model00a_discrim_children <- lm(dprime ~ 1, data =
  discrim_trained_talker[discrim_trained_talker$Time
  == "discrim2" & discrim_trained_talker$Group == "
  Children",])
```

Table 6: Intercept only linear regression model with the discrimination immediate posttest as the dependent variable. Child data only.

	Estimate	Std. Error	t value	p value
(Intercept)	0.77	0.15	4.97	0.00

1.2.6 Adults discriminated sounds above chance immediately after training.

```
model00a_discrim_adults <- lm(dprime ~ 1, data =
  discrim_trained_talker[discrim_trained_talker$Time
  == "discrim2" & discrim_trained_talker$Group == "
  Adults",])
```

Table 7: Intercept only linear regression model with the discrimination immediate posttest as the dependent variable. Adult data only.

	Estimate	Std. Error	t value	Pr(> t)
(Intercept)	1.46	0.12	11.91	0.00

1.2.7 Participants discriminated above chance after a one-day delay.

```
model00b_discrim <- lm(dprime ~ 1, data =
  discrim_trained_talker[discrim_trained_talker$Time
  == "discrim3",])
```

Table 8: Intercept only linear regression model with the discrimination next-day posttest as the dependent variable.

	Estimate	Std. Error	t value	p value
(Intercept)	1.35	0.15	9.26	0.00

1.2.8 Children discriminated the sounds above chance after a one-day delay.

```
model00b_discrim_children <- lm(dprime ~ 1, data =
  discrim_trained_talker[discrim_trained_talker$Time
  == "discrim3" & discrim_trained_talker$Group == "
  Children",])
```

Table 9: Intercept only linear regression model with the discrimination next-day posttest as the dependent variable. Child data only.

	Estimate	Std. Error	t value	p value
(Intercept)	0.88	0.20	4.49	0.00

1.2.9 Adults discriminated the sounds above chance after a one-day delay.

```
model00b_discrim_adults <- lm(dprime ~ 1, data =  
  discrim_trained_talker[discrim_trained_talker$Time  
  == "discrim3" & discrim_trained_talker$Group == "  
  Adults",])
```

Table 10: Intercept only linear regression model with the discrimination next-day posttest as the dependent variable. Adult data only.

	Estimate	Std. Error	t value	p value
(Intercept)	1.79	0.17	10.46	0.00

1.2.10 Participants identified the sounds above chance after a one-day delay.

```
model0a_id <- glmer(correctRC ~ 1 + (1|subject_nr),  
  data = ID_trained_talker[ID_trained_talker$block ==  
  "ID_test2",], family='binomial')
```

Table 11: Intercept only mixed effects logistic regression model with the next-day identification posttest as dependent variable.

	Estimate	Std. Error	z value	p value
(Intercept)	2.08	0.21	10.04	0.00

1.2.11 Children identified the sounds above chance after a one-day delay.

```
model0a_id_children <- glmer(correctRC ~ 1 + (1|  
  subject_nr), data = ID_trained_talker[  
  ID_trained_talker$block == "ID_test2" &  
  ID_trained_talker$Group == "Children",], family=  
  'binomial')
```

Table 12: Intercept only mixed effects logistic regression model with the next-day identification posttest as dependent variable. Child data only.

	Estimate	Std. Error	z value	p value
(Intercept)	1.62	0.24	6.62	0.00

1.2.12 Adults identified the sounds above chance after a one-day delay.

```
model0a_id_adults <- glmer(correctRC ~ 1 + (1|
  subject_nr), data = ID_trained_talker[
  ID_trained_talker$block == "ID_test2" &
  ID_trained_talker$Group == "Adults",], family='
  binomial')
```

Table 13: Intercept only mixed effects logistic regression model with the next-day identification posttest as dependent variable. Adult data only.

	Estimate	Std. Error	z value	p value
(Intercept)	2.53	0.31	8.16	0.00

1.2.13 Identification performance predicted by age.

```
modella_id <- glmer(correctRC ~ block*Age + (block_con
  ||subject_nr), data = ID_trained_talker, family = "
  binomial")
```

Table 14: Mixed effects logistic regression model with trained talker.

	Estimate	Std. Error	z value	p value
(Intercept)	1.11	0.32	3.49	0.00
Time	0.57	0.25	2.28	0.02
Age	0.03	0.01	3.10	0.00
Time:Age	-0.02	0.01	-1.99	0.05

1.2.14 Exploratory nested model to test effects of age at both identification time points.

```
model1b_id_nested <- glmer(correctRC ~ block/Age + (
  block_con || subject_nr), data = ID_trained_talker,
  family = "binomial")
```

Table 15: Mixed effects logistic regression model with trained talker. Age nested within time.

	Estimate	Std. Error	z value	p value
(Intercept)	1.11	0.32	3.49	0.00
Time	0.57	0.25	2.28	0.02
Time Immediate posttest:Age	0.04	0.01	3.60	0.00
Time Next-day posttest:Age	0.02	0.01	2.12	0.03

1.2.15 Identification performance predicted by age, discrimination pretest, and time.

```
modella_id_cov <- glmer(correctRC ~ block*Age*discrim1
  + (block_con || subject_nr), data = id_cov, family = "
  binomial", control = glmerControl(optimizer = "
  bobyqa", optCtrl = list(maxfun = 200000)))
```

Table 16: Mixed effects logistic regression model with trained talker. Discrimination pretest added as fixed factor.

	Estimate	Std. Error	z value	p value
(Intercept)	1.64	0.28	5.76	0.00
Time	0.53	0.33	1.61	0.11
Age	-0.02	0.01	-1.43	0.15
discrim1	0.48	0.39	1.22	0.22
Time:Age	-0.01	0.01	-0.69	0.49
Time:discrim1	0.21	0.47	0.45	0.66
Age:discrim1	0.03	0.01	2.46	0.01
Time:Age:discrim1	-0.02	0.02	-0.96	0.34

1.2.16 Identification performance in children predicted by discrimination pretest and time.

```
modellb_id_cov_children <- glmer(correctRC ~ block*
  discrim1 + (block|subject_nr), data = id_cov[
  id_cov$Group == "Children",], family = "binomial")
```

Table 17: Mixed effects logistic regression model with trained talker. Discrim1 = discrimination pretest. Child data only.

	Estimate	Std. Error	z value	p value
(Intercept)	1.36	0.21	6.65	0.00
Time	0.38	0.17	2.23	0.03
discrim1	0.81	0.34	2.36	0.02
Time:discrim1	0.23	0.30	0.76	0.45

1.2.17 Identification performance in adults predicted by discrimination pretest and time.

```
modellb_id_cov_adults2 <- glmer(correctRC ~ block*
  discrim1 + (block_con || subject_nr), data = id_cov[
  id_cov$Group == "Adults",], family = "binomial")
```

Table 18: Mixed effects logistic regression model with trained talker. Discrim1 = discrimination pretest. Adult data only.

	Estimate	Std. Error	z value	p value
(Intercept)	0.94	0.31	3.00	0.00
Time	0.47	0.52	0.91	0.36
discrim1	1.79	0.31	5.69	0.00
Time:discrim1	-0.72	0.54	-1.32	0.19

1.2.18 Discrimination performance predicted by age and time.

```
modell_discrim <- lmer(dprime ~ Time*Age + (1|
  subject_nr), data = discrim_trained_talker)
```


Table 19: Mixed effects model of discrimination data with trained talker.

	Estimate	Std. Error	df	t value	p value
(Intercept)	0.32	0.18	43.00	1.79	0.08
Time2-1	0.76	0.22	86.00	3.52	0.00
Time3-2	0.06	0.22	86.00	0.27	0.79
Age	0.03	0.01	43.00	4.53	0.00
Time2-1:Age	-0.01	0.01	86.00	-1.35	0.18
Time3-2:Age	0.01	0.01	86.00	0.89	0.37

1.2.19 Discrimination posttest performance predicted by age, discrimination pretest, and time.

```
modell_pre_discrim <- lmer(dprime ~ discrim1*Time*Age +
  (1|subject_nr), data = discrim_ancova)
```

Table 20: Mixed effects model of discrimination data with trained talker. Pretest included as a fixed factor. Discrim1 = pretest, time includes two posttests.

	Estimate	Std. Error	df	t value	p value
(Intercept)	0.61	0.21	41.00	2.93	0.01
discrim1	0.67	0.28	41.00	2.42	0.02
Time	0.21	0.22	41.00	0.96	0.34
Age	0.01	0.01	41.00	1.48	0.15
discrim1:Time	-0.07	0.28	41.00	-0.23	0.82
discrim1:Age	-0.01	0.01	41.00	-0.73	0.47
Time:Age	-0.00	0.01	41.00	-0.53	0.60
discrim1:Time:Age	0.01	0.01	41.00	1.05	0.30

1.3 Generalization

1.3.1 Participants identified the sounds with an untrained talker's voice at above chance levels.

```
model2a_id <- glmer(correctRC ~ 1 + (1|subject_nr),
  data = ID_untrained_talker, family = "binomial")
```

Table 21: Intercept only mixed effects logistic regression model with the generalization identification posttest as dependent variable.

	Estimate	Std. Error	z value	p value
(Intercept)	0.59	0.11	5.52	0.00

1.3.2 Children identified the sounds with an untrained talker's voice at above chance levels.

```
model2a_id_children <- glmer(correctRC ~ 1 + (1|
  subject_nr), data = ID_untrained_talker[
  ID_untrained_talker$Group == "Children",], family =
  "binomial")
```

Table 22: Intercept only mixed effects logistic regression model with the generalization identification posttest as dependent variable. Child data only.

	Estimate	Std. Error	z value	p value
(Intercept)	0.45	0.13	3.44	0.00

1.3.3 Adults identified the sounds with an untrained talker's voice at above chance levels.

```
model2a_id_adults <- glmer(correctRC ~ 1 + (1|
  subject_nr), data = ID_untrained_talker[
  ID_untrained_talker$Group == "Adults",], family = "
  binomial")
```

Table 23: Intercept only mixed effects logistic regression model with the generalization identification posttest as dependent variable. Adult data only.

	Estimate	Std. Error	z value	p value
(Intercept)	0.73	0.17	4.38	0.00

1.3.4 Generalization in identification task predicted by age.

```
model2_id <- glmer(correctRC ~ Age + (1|subject_nr),
  data = ID_untrained_talker, family = "binomial")
```

Table 24: Mixed effects logistic regression model with the generalization identification posttest as dependent variable and age as predictor.

	Estimate	Std. Error	z value	p value
(Intercept)	0.29	0.20	1.46	0.14
Age	0.01	0.01	1.70	0.09

1.3.5 Generalization in identification task predicted by age and discrimination pretest.

```
model3_id <- glmer(correctRC ~ Age*discrim1 + (1|
  subject_nr), data = id_cov_ut, family = "binomial",
  control = glmerControl(optimizer = "bobyqa", optCtrl
    = list(maxfun = 200000)))
```

Table 25: Mixed effects logistic regression model with the generalization identification posttest as dependent variable and age and discrimination pretest (discrim1) as predictors.

	Estimate	Std. Error	z value	p value
(Intercept)	0.44	0.22	1.95	0.05
Age	-0.00	0.01	-0.32	0.75
discrim1	0.19	0.29	0.65	0.52
Age:discrim1	0.01	0.01	0.72	0.47

1.3.6 Participants discriminated the sounds with an untrained talker's voice at above chance levels.

```
model2a_discrim <- lm(dprime ~ 1, data =
  discrim_untrained_talker)
```

Table 26: Intercept only linear regression model with the generalization discrimination posttest as dependent variable.

	Estimate	Std. Error	t value	p value
(Intercept)	0.54	0.09	5.94	0.00

1.3.7 Children discriminated the sounds with an untrained talker's voice at above chance levels.

```
model2a_discrim_children <- lm(dprime ~ 1, data =  
  discrim_untrained_talker [  
    discrim_untrained_talker$Group == "Children" ,])
```

Table 27: Intercept only linear regression model with the generalization discrimination posttest as dependent variable. Child data only.

	Estimate	Std. Error	t value	p value
(Intercept)	0.33	0.11	3.04	0.01

1.3.8 Adults discriminated the sounds with an untrained talker's voice at above chance levels.

```
model2a_discrim_adults <- lm(dprime ~ 1, data =  
  discrim_untrained_talker [  
    discrim_untrained_talker$Group == "Adults" ,])
```

Table 28: Intercept only linear regression model with the generalization discrimination posttest as dependent variable. Adult data only.

	Estimate	Std. Error	t value	p value
(Intercept)	0.75	0.13	5.56	0.00

1.3.9 Generalization in discrimination task predicted by age.

```
model2_discrim <- lm(dprime ~ Age, data =  
  discrim_untrained_talker)
```

Table 29: Linear regression model with the generalization discrimination posttest as dependent variable and age as predictor.

	Estimate	Std. Error	t value	p value
(Intercept)	0.07	0.16	0.44	0.66
Age	0.02	0.01	3.46	0.00

1.3.10 Generalization in discrimination task predicted by age and discrimination pretest.

```
model3_discrim <- lm(dprime ~ Age*discrim1, data =
  discrim_ut_cov)
```

Table 30: Linear regression model with the generalization discrimination posttest as dependent variable and age and discrimination pretest (discrim1) as predictors.

	Estimate	Std. Error	t value	p value
(Intercept)	0.16	0.12	1.40	0.16
Age	0.01	0.00	1.38	0.17
discrim1	0.25	0.15	1.63	0.11
Age:discrim1	0.00	0.00	0.53	0.60

2 Individual differences

2.0.1 Individual predictors of discrimination performance.

```
modell1_discrim_inddif <- lmer(dprime ~ Time/(Group/(
  Sound_Blending*Nonword_Repetition*pitch_perception))
  + (1|subject_nr), data = discrim_scaled)
```

Table 31: Linear mixed effects model for discrimination performance. Predictors included time (pretest = 1, immediate posttest = 2, next-day posttest = 3), group (adults, children), non-word repetition (NWR), sound blending (SB), and pitch perception (PP).

	Estimate	Std. Error	df	t value	p value
(Intercept)	0.64	0.14	60.00	4.58	0.00
Time2	0.39	0.14	58.00	2.73	0.01
Time3	0.70	0.14	58.00	4.84	0.00
Time1:Group	-0.75	0.28	60.00	-2.69	0.01
Time2:Group	-0.47	0.28	60.00	-1.68	0.10
Time3:Group	-0.50	0.28	60.00	-1.78	0.08
Time1:GroupAdults:SB	0.08	0.21	60.00	0.37	0.71

Time2:GroupAdults:SB	0.40	0.21	60.00	1.85	0.07
Time3:GroupAdults:SB	0.45	0.21	60.00	2.09	0.04
Time1:GroupChildren:SB	0.07	0.24	60.00	0.28	0.78
Time2:GroupChildren:SB	0.16	0.24	60.00	0.67	0.51
Time3:GroupChildren:SB	0.16	0.24	60.00	0.67	0.51
Time1:GroupAdults:NWR	-0.04	0.19	60.00	-0.23	0.82
Time2:GroupAdults:NWR	0.07	0.19	60.00	0.34	0.73
Time3:GroupAdults:NWR	-0.06	0.19	60.00	-0.31	0.76
Time1:GroupChildren:NWR	-0.14	0.33	60.00	-0.41	0.68
Time2:GroupChildren:NWR	0.07	0.33	60.00	0.21	0.83
Time3:GroupChildren:NWR	0.88	0.33	60.00	2.63	0.01
Time1:GroupAdults:PP	-0.41	0.20	60.00	-2.01	0.05
Time2:GroupAdults:PP	-0.06	0.20	60.00	-0.32	0.75
Time3:GroupAdults:PP	-0.05	0.20	60.00	-0.24	0.81
Time1:GroupChildren:PP	-0.21	0.20	60.00	-1.09	0.28
Time2:GroupChildren:PP	-0.22	0.20	60.00	-1.14	0.26
Time3:GroupChildren:PP	0.10	0.20	60.00	0.51	0.61
Time1:GroupAdults:SB:NWR	-0.08	0.20	60.00	-0.40	0.69
Time2:GroupAdults:SB:NWR	-0.17	0.20	60.00	-0.86	0.40
Time3:GroupAdults:SB:NWR	-0.42	0.20	60.00	-2.10	0.04
Time1:GroupChildren:SB:NWR	-0.30	0.38	60.00	-0.78	0.44
Time2:GroupChildren:SB:NWR	0.07	0.38	60.00	0.19	0.85
Time3:GroupChildren:SB:NWR	0.76	0.38	60.00	2.00	0.05
Time1:GroupAdults:SB:PP	0.43	0.22	60.00	1.94	0.06
Time2:GroupAdults:SB:PP	0.16	0.22	60.00	0.72	0.47
Time3:GroupAdults:SB:PP	-0.02	0.22	60.00	-0.09	0.93
Time1:GroupChildren:SB:PP	0.08	0.19	60.00	0.44	0.66
Time2:GroupChildren:SB:PP	-0.18	0.19	60.00	-0.95	0.35
Time3:GroupChildren:SB:PP	-0.26	0.19	60.00	-1.35	0.18
Time1:GroupAdults:NWR:PP	-0.62	0.36	60.00	-1.71	0.09
Time2:GroupAdults:NWR:PP	0.23	0.36	60.00	0.64	0.53
Time3:GroupAdults:NWR:PP	-0.23	0.36	60.00	-0.62	0.54
Time1:GroupChildren:NWR:PP	-0.01	0.44	60.00	-0.02	0.98
Time2:GroupChildren:NWR:PP	0.06	0.44	60.00	0.13	0.90
Time3:GroupChildren:NWR:PP	1.12	0.44	60.00	2.54	0.01
Time1:GroupAdults:SB:NWR:PP	-0.05	0.32	60.00	-0.15	0.88
Time2:GroupAdults:SB:NWR:PP	-0.56	0.32	60.00	-1.76	0.08
Time3:GroupAdults:SB:NWR:PP	-0.52	0.32	60.00	-1.66	0.10

Time1:GroupChildren:SB:NWR:PP	-0.17	0.44	60.00	-0.39	0.70
Time2:GroupChildren:SB:NWR:PP	-0.41	0.44	60.00	-0.93	0.36
Time3:GroupChildren:SB:NWR:PP	0.44	0.44	60.00	1.00	0.32

2.0.2 Individual predictors of identification performance.

```
model3b_id <- glmer(correctRC ~ block/(Group/(
  Nonword_Repetition_s*Sound_Blending_s*
  pitch_perception_s)) + (1|subject_nr), data =
  ID_trained_talker, family = "binomial", control =
  glmerControl(optimizer = "bobyqa", optCtrl = list(
    maxfun = 200000)))
```

Table 32: Mixed effects logistic regression model for identification performance. Predictors included time (immediate posttest = 1, next-day posttest = 2), group (adults, children), non-word repetition (NWR), sound blending (SB), and pitch perception (PP).

	Estimate	Std. Error	z value	p value
(Intercept)	1.91	0.17	11.29	0.00
Time	0.18	0.13	1.41	0.16
Time1:Group	-1.15	0.35	-3.25	0.00
Time2:Group	-0.16	0.36	-0.44	0.66
Time1:GroupAdults:NWR	-0.34	0.25	-1.38	0.17
Time2:GroupAdults:NWR	0.14	0.25	0.56	0.58
Time1:GroupChildren:NWR	0.18	0.40	0.45	0.65
Time2:GroupChildren:NWR	1.39	0.45	3.12	0.00
Time1:GroupAdults:SB	0.66	0.30	2.17	0.03
Time2:GroupAdults:SB	0.89	0.28	3.12	0.00
Time1:GroupChildren:SB	0.06	0.29	0.20	0.84
Time2:GroupChildren:SB	0.10	0.29	0.32	0.75
Time1:GroupAdults:PP	-0.42	0.28	-1.51	0.13
Time2:GroupAdults:PP	-0.28	0.26	-1.08	0.28
Time1:GroupChildren:PP	-0.24	0.23	-1.03	0.30
Time2:GroupChildren:PP	0.33	0.26	1.30	0.19
Time1:GroupAdults:NWR:SB	-0.28	0.27	-1.03	0.30
Time2:GroupAdults:NWR:SB	-0.58	0.26	-2.21	0.03
Time1:GroupChildren:NWR:SB	0.24	0.45	0.53	0.60
Time2:GroupChildren:NWR:SB	0.99	0.48	2.08	0.04
Time1:GroupAdults:NWR:PP	-1.36	0.50	-2.73	0.01
Time2:GroupAdults:NWR:PP	-0.18	0.48	-0.37	0.71
Time1:GroupChildren:NWR:PP	-0.02	0.52	-0.04	0.97
Time2:GroupChildren:NWR:PP	1.24	0.58	2.14	0.03
Time1:GroupAdults:SB:PP	0.98	0.31	3.13	0.00
Time2:GroupAdults:SB:PP	0.55	0.30	1.83	0.07
Time1:GroupChildren:SB:PP	-0.13	0.23	-0.57	0.57
Time2:GroupChildren:SB:PP	0.04	0.23	0.15	0.88
Time1:GroupAdults:NWR:SB:PP	0.10	0.43	0.24	0.81
Time2:GroupAdults:NWR:SB:PP	-0.67	0.42	-1.59	0.11
Time1:GroupChildren:NWR:SB:PP	-0.34	0.51	-0.67	0.50
Time2:GroupChildren:NWR:SB:PP	0.61	0.55	1.11	0.27