

L1 phonetic drift during adult L2 acquisition

Speech rate analysis

Joseph V. Casillas

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Overview

A common finding in the second language (L2) speech literature is that adults who learn another language typically retain a non-native accent in the target language (TL). L1 to L2 cross-linguistic influence is attested to some degree in learners of all languages at all proficiency levels, showing that learners tend to produce L2 sounds through the filter of their L1. With time and effort, L2 learners develop TL-specific phonetic categories. Recent research suggests that the cross-linguistic influence that occurs in bilingual speech may be bidirectional, that is to say, L2 phonetic category formation may have behavioral consequences for L1 categories. This project explores the production of native English speaking adult L2 learners of Spanish. Specifically, it tracks the phonological acquisition of stop contrasts over the course of a domestic immersion program in order to shed light on how L2 phonological acquisition affects L1 phonology.

The problem

- Learning to produce and perceive L2 sounds is hard
- During early stages of learning we produce target language sounds using L1 phonology

Theoretical issues

Opposing viewpoints:

- **Speech Learning Model** (SLM-r: Flege and Bohn (2021))
 - L1 and L2 phonetic categories share the same phonetic space
 - Bidirectional influence, i.e., learning L2 sounds can affect L1 sounds

- **Second Language Linguistic Perception Model** (L2LP: Van Leussen and Escudero (2015))
 - During early stages of learning L1 phonological system is copied
 - L2 sounds develop independently of L1 system
- As predicted by the SLM-r, there is growing evidence that **phonetic drift** (PD) occurs during L2 learning (See Chang 2012, 2013; Lang and Davidson 2019; Tobin, Nam, and Fowler 2017)
- PD refers to changes in L1 (native) categories that take place during the process of learning novel sounds in an L2 .
- The SLM-r predicts phonetic drift, the L2LP suggests it should not occur

Present study

- We explore the possibility that L2 learning can affect L1 speech using data collected in a domestic immersion program
- Specifically, we analyze speech fluency data (articulation rate, avg. syllable duration) in a pre/post test paradigm

Method

- Participants: 30 L1 English adult learners of Spanish participating in a domestic immersion program
- The program: 7-week domestic immersion, L1 use prohibited
- Data: We analyze pre and post program interviews conducted in Spanish and English
- Using Praat we extracted speech fluency metrics to shed light on how L2 immersive learning affects L1 speech

Data prep

Load libraries and helper functions

```

source(here::here("scripts", "r", "01_helpers.R"))

theme_set(
  theme_bw(base_size = 12, base_family = "Palatino") +
  theme(
    axis.title.y = element_text(size = rel(0.9), hjust = 0.95),
    axis.title.x = element_text(size = rel(0.9), hjust = 0.95),
    panel.grid.major = element_line(colour = "grey90", linewidth = 0.15),
    panel.grid.minor = element_line(colour = "grey90", linewidth = 0.15),
    strip.background = element_blank()
  )
)

```

Load data

```

spr_en <- read_csv(here("data", "raw", "speech_rate_en.csv"))
spr_sp <- read_csv(here("data", "raw", "speech_rate_sp.csv"))

```

Tidy data

```

dat <- bind_rows(
  spr_en |>
    clean_names() |>
    separate(col = soundname, into = c("id", "language"), sep = "_") |>
    separate(col = id, into = c("id", "year"), sep = "-4") |>
    separate(col = id, into = c("id", "phase"), sep = "[0-9](?=p)") |>
    mutate(language = "English"),

  spr_sp |>
    clean_names() |>
    separate(col = soundname, into = c("id", "phase"), sep = 6) |>
    separate(
      col = phase,
      into = c("phase", "year"),
      sep = "(?<=[a-zA-Z])\\s*(?=[0-9])"
    ) |>
    mutate(language = "Spanish") |>
    select(id, phase, year, language, everything())

```

```

) |>
  rename(
    n_syllables = nsyll,
    n_pauses = npause,
    recording_duration = dur_s,
    phonation_time = phonationtime_s,
    sr = speechrate_nsyll_dur,
    ar = articulation_rate_nsyll_phonationtime,
    asd = asd_speakingtime_nsyll
  ) |>
  pivot_longer(
    cols = n_syllables:asd,
    names_to = "metric",
    values_to = "val"
  ) |>
  mutate(
    phase = fct_relevel(phase, "pre"),
    metric = fct_relevel(metric,
      "n_syllables", "n_pauses", "recording_duration", "phonation_time",
      "sr", "ar", "asd")
  ) |>
  write_csv(here("data", "tidy", "spr_tidy.csv"))

glimpse(dat)

```

```

Rows: 840
Columns: 6
$ id      <chr> "aka04", "aka04", "aka04", "aka04", "aka04", "aka04", "aka04"~
$ phase   <fct> post, post, post, post, post, post, post, pre, pre, pre, pre,~
$ year    <chr> "2019", "2019", "2019", "2019", "2019", "2019", "2019", "2019~
$ language <chr> "English", "English", "English", "English", "English", "Engli~
$ metric  <fct> n_syllables, n_pauses, recording_duration, phonation_time, sr~
$ val     <dbl> 411.000, 36.000, 109.500, 85.370, 3.750, 4.810, 0.208, 251.00~

```

Design

Variables

- id: unique participant identification string
- phase: stage of data collection (pre, post)

- year: year of immersion program
- language: language spoken during interview (Spanish, English)

Metrics

- n_syllables: number of syllables produced
- n_pauses: number of pauses
- recording_duration: total time (s) of recording
- phonation_time: total speaking time (s)
- sr: speech rate ($n_syllables / recording_duration$)
- ar: articulation rate ($n_syllables / phonation_time$)
- asd: average syllable duration ($phonation_time / n_syllables$)

Exploratory plots

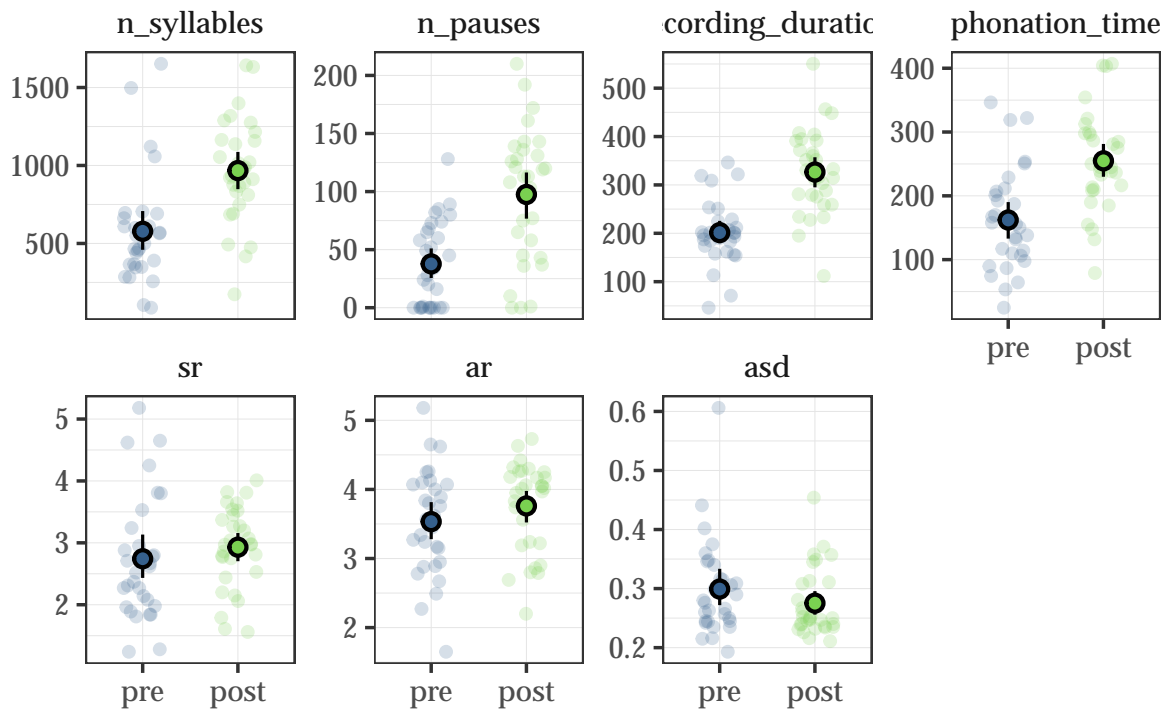
Spanish interview

OPI-style oral assessment in which participants are asked a range of questions.

```
dat |>
  filter(language == "Spanish") |>
  ggplot() +
  aes(x = phase, y = val) +
  facet_wrap(. ~ metric, scales = "free_y", ncol = 4) +
  geom_jitter(
    aes(color = phase),
    height = 0, width = 0.2, alpha = 0.2, show.legend = F
  ) +
  stat_summary(
    aes(fill = phase),
    fun.data = mean_cl_boot, geom = "pointrange", pch = 21,
    show.legend = F
  ) +
  scale_fill_viridis_d(option = "D", begin = 0.3, end = 0.8) +
  scale_color_viridis_d(option = "D", begin = 0.3, end = 0.8) +
  labs(
    title = "Speech fluency metrics",
    subtitle = "Spanish production as a function of phase in immersion program",
    x = NULL, y = NULL
  )
```

Speech fluency metrics

Spanish production as a function of phase in immersion program



English

Participants respond to question “what does learning another language mean to you?”

```
dat |>
  filter(language == "English") |>
  ggplot() +
  aes(x = phase, y = val) +
  facet_wrap(. ~ metric, scales = "free_y", ncol = 4) +
  geom_jitter(
    aes(color = phase),
    height = 0, width = 0.2, alpha = 0.2, show.legend = F
  ) +
  stat_summary(
    aes(fill = phase),
    fun.data = mean_cl_boot, geom = "pointrange", pch = 21,
    show.legend = F
  )
```

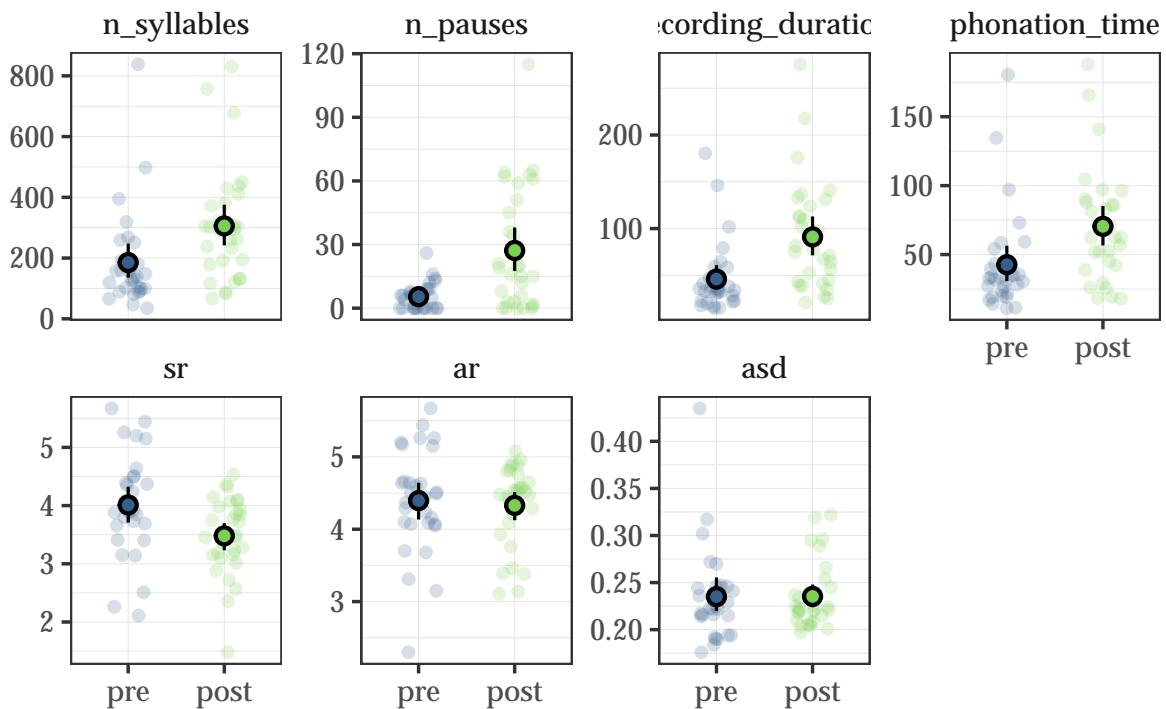
```

) +
scale_fill_viridis_d(option = "D", begin = 0.3, end = 0.8) +
scale_color_viridis_d(option = "D", begin = 0.3, end = 0.8) +
labs(x = NULL, y = NULL) +
labs(
  title = "Speech fluency metrics",
  subtitle = "English production as a function of phase in immersion program",
  x = NULL, y = NULL
)

```

Speech fluency metrics

English production as a function of phase in immersion program



Models

```

# Scale continuous variables
dat_z <- dat |>

```

```

group_by(language, metric) |>
mutate(val_z = scale_this(val))

bf_raw <- bf(
  val ~ 0 + phase:language +
    (1 + phase:language | id)
)

bf_z <- bf(
  val_z ~ 0 + phase:language +
    (1 + phase:language | id)
)

```

Number of syllables

```

get_prior(
  formula = bf_raw,
  family = poisson(link = "log"),
  data = filter(dat_z, metric == "n_syllables")
) |>
select(prior, class, coef) |>
knitr::kable()

```

prior	class	coef
	b	
	b	phasepost:languageEnglish
	b	phasepost:languageSpanish
	b	phasepre:languageEnglish
	b	phasepre:languageSpanish
lkj(1)	cor	
	cor	
student_t(3, 0, 2.5)	sd	
	sd	
	sd	Intercept
	sd	phasepost:languageEnglish
	sd	phasepost:languageSpanish
	sd	phasepre:languageEnglish
	sd	phasepre:languageSpanish


```

n_syllables_prior <- c(
  prior(normal(5, 1), class = "b"),
  prior(lkj(1), class = "cor"),
  prior(exponential(1), class = "sd")
)

mod_sr_n_syllables <- brm(
  formula = bf_raw,
  family = poisson(link = "log"),
  prior = n_syllables_prior,
  sample_prior = "no",
  chains = 4, iter = 2000, warmup = 1000,
  cores = 4, threads = threading(2),
  backend = "cmdstanr",
  control = list(adapt_delta = 0.99, max_treedepth = 12),
  data = filter(dat_z, metric == "n_syllables"),
  file = here("models", "mod_sr_n_syllables")
)

n_syllables_post <- as_tibble(mod_sr_n_syllables) |>
  transmute(
    English_pre = exp(`b_phasepre:languageEnglish`),
    English_post = exp(`b_phasepost:languageEnglish`),
    Spanish_pre = exp(`b_phasepre:languageSpanish`),
    Spanish_post = exp(`b_phasepost:languageSpanish`)
  ) |>
  pivot_longer(cols = everything()) |>
  separate(name, into = c("language", "phase"), sep = "_") |>
  mutate(
    phase = str_to_title(phase),
    phase = fct_relevel(phase, "Pre")
  )

n_syllables_post |>
  ggplot() +
  aes(y = language, x = value, group = phase) +
  geom_point(
    data = filter(dat_z, metric == "n_syllables") |>
      mutate(phase = str_to_title(phase), phase = fct_relevel(phase, "Pre")),
    mapping = aes(y = language, x = val, fill = phase),
    position = ggpp::position_dodgenudge(
      x = 0, direction = "split", width = 0.5
    )
  )

```

```

),
  pch = 21, alpha = 0.4, size = 3, color = "white", stroke = 1
) +
stat_halfeye(
  aes(fill = phase),
  position = ggpp::position_dodgenudge(
    y = 0.06, direction = "split", width = 0.5),
  pch = 21, point_fill = "white", show.legend = F
) +
scale_fill_viridis_d(name = NULL, option = "D", begin = 0.4, end = 0.8) +
scale_color_viridis_d(name = NULL, option = "D", begin = 0.4, end = 0.8) +
labs(y = NULL, x = "Syllables\n") +
guides(fill = guide_legend(override.aes = list(alpha = 1, size = 3))) +
theme(
  legend.position = "inside", legend.justification.inside = c(1, 0),
  legend.background = element_blank(),
  axis.text.y = element_text(angle = 90, hjust = 0.5, size = 16),
  axis.text.x = element_text(size = 14),
  axis.title.x = element_text(size = 16),
  legend.text = element_text(size = 14)
)

```

Registered S3 methods overwritten by 'ggpp':

```

method          from
heightDetails.titleGrob ggplot2
widthDetails.titleGrob  ggplot2

```

```

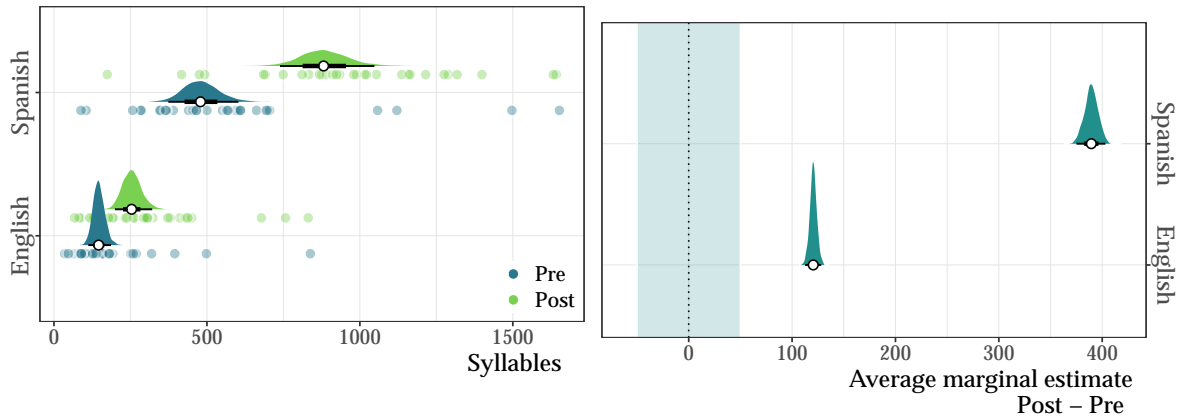
avg_comparisons(
  model = mod_sr_n_syllables,
  variables = "phase",
  by = "language"
) |>
posterior_draws() |>
ggplot() +
aes(x = draw, y = language) +
geom_rect(
  inherit.aes = F,
  data = tibble(xmin = -50, xmax = 50),
  aes(xmin = xmin, xmax = xmax, ymin = -Inf, ymax = Inf),
  fill = my_col(b = 0.5, n = 1, a = 0.2), color = "white",
) +

```

```

geom_vline(xintercept = 0, lty = 3) +
stat_halfeye(
  aes(alpha = after_stat(abs(x) < 50)),
  slab_fill = my_col(b = 0.5, n = 1), slab_color = "white",
  show.legend = F, pch = 21, point_fill = "white"
) +
scale_alpha_manual(values = c(1, 0.4)) +
scale_y_discrete(position = "right") +
coord_cartesian(xlim = c(-60, NA)) +
labs(x = "Average marginal estimate\nPost - Pre", y = NULL) +
theme(
  axis.text.y.right = element_text(angle = -90, hjust = 0.5, size = 16),
  axis.text.x = element_text(size = 14),
  axis.title.x = element_text(size = 16)
)

```



- (a) Number of syllables produced as a function of language (English, Spanish) and phase (pre, post). (b) Average marginal estimate of the difference between 'pre' and 'post' for each language.

Figure 1: Syllables produced

```

bind_rows(
n_syllables_post |>
  group_by(language, phase) |>
  median_hdi(value) |>
  mutate(across(value:.upper, \(x) specify_decimal(x, k = 2))) |>
  transmute(
    Language = glue("{language}: {phase}"),
    Estimate = value,

```

```
HDI = glue("[{.lower}, {.upper}]")
) ,

avg_comparisons(
  model = mod_sr_n_syllables,
  variables = "phase",
  by = "language"
) |>
as_tibble() |>
mutate(
  contrast = str_remove_all(contrast, "mean\\(|\\|\\|)"),
  contrast = str_to_title(contrast)
) |>
mutate(across(estimate:conf.high, \(x) specify_decimal(x, k = 2))) |>
transmute(
  Language = glue("{language}: {contrast}"),
  Estimate = estimate,
  HDI = glue("[{conf.low}, {conf.high}]")
)
) |>
tt(width = 0.75) |>
style_tt(j = 2:3, align = "r") |>
group_tt(i = list("Average marginal estimate" = 5)) |>
style_tt(i = 0, line = "t", line_color = "black", line_width = 0.1) |>
style_tt(i = 4, line = "b", line_color = "black", line_width = 0.05) |>
style_tt(i = 7, line = "b", line_color = "black", line_width = 0.1)
```

Number of pauses

```
get_prior(
  formula = bf_raw,
  family = poisson(link = "log"),
  data = filter(dat_z, metric == "n_pauses")
) |>
  select(prior, class, coef) |>
  knitr::kable()
```

Table 2: Number of syllables

Language	Estimate	HDI
English: Pre	145.99	[109.85, 183.60]
English: Post	253.74	[196.62, 317.39]
Spanish: Pre	478.91	[370.56, 596.27]
Spanish: Post	881.32	[739.35, 1047.89]
Average marginal estimate		
English: Post - Pre	120.46	[112.57, 128.22]
Spanish: Post - Pre	389.46	[375.11, 403.13]

prior	class	coef
	b	
	b	phasepost:languageEnglish
	b	phasepost:languageSpanish
	b	phasepre:languageEnglish
	b	phasepre:languageSpanish
lkj(1)	cor	
	cor	
student_t(3, 0, 2.5)	sd	
	sd	
	sd	Intercept
	sd	phasepost:languageEnglish
	sd	phasepost:languageSpanish
	sd	phasepre:languageEnglish
	sd	phasepre:languageSpanish

```

n_pauses_prior <- c(
  prior(normal(4, 1), class = "b"),
  prior(lkj(1), class = "cor"),
  prior(exponential(1), class = "sd")
)

mod_sr_n_pauses <- brm(
  formula = bf_raw,
  family = poisson(link = "log"),

```

```

prior = n_syllables_prior,
sample_prior = "no",
chains = 4, iter = 2000, warmup = 1000,
cores = 4, threads = threading(2),
backend = "cmdstanr",
control = list(adapt_delta = 0.99, max_treedepth = 12),
data = filter(dat_z, metric == "n_pauses"),
file = here("models", "mod_sr_n_pauses")
)

```

```

n_pauses_post <- as_tibble(mod_sr_n_pauses) |>
  transmute(
    English_pre = exp(`b_phasepre:languageEnglish`),
    English_post = exp(`b_phasepost:languageEnglish`),
    Spanish_pre = exp(`b_phasepre:languageSpanish`),
    Spanish_post = exp(`b_phasepost:languageSpanish`)
  ) |>
  pivot_longer(cols = everything()) |>
  separate(name, into = c("language", "phase"), sep = "_") |>
  mutate(
    phase = str_to_title(phase),
    phase = fct_relevel(phase, "Pre")
  )

n_pauses_post |>
  ggplot() +
  aes(y = language, x = value, group = phase) +
  geom_point(
    data = filter(dat_z, metric == "n_pauses") |>
      mutate(phase = str_to_title(phase), phase = fct_relevel(phase, "Pre")),
    mapping = aes(y = language, x = val, fill = phase),
    position = ggpp::position_dodgenudge(
      x = 0, direction = "split", width = 0.5
    ),
    pch = 21, alpha = 0.4, size = 3, color = "white", stroke = 1
  ) +
  stat_halfeye(
    aes(fill = phase),
    position = ggpp::position_dodgenudge(
      y = 0.06, direction = "split", width = 0.5),
    pch = 21, point_fill = "white", show.legend = F
  ) +

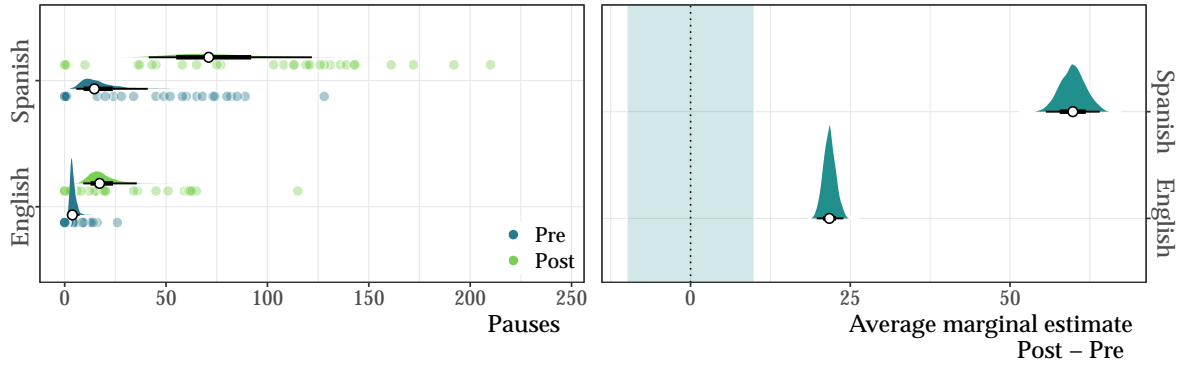
```

```

scale_fill_viridis_d(name = NULL, option = "D", begin = 0.4, end = 0.8) +
scale_color_viridis_d(name = NULL, option = "D", begin = 0.4, end = 0.8) +
labs(y = NULL, x = "Pauses\n") +
guides(fill = guide_legend(override.aes = list(alpha = 1, size = 3))) +
theme(
  legend.position = "inside", legend.justification.inside = c(1, 0),
  legend.background = element_blank(),
  axis.text.y = element_text(angle = 90, hjust = 0.5, size = 16),
  axis.text.x = element_text(size = 14),
  axis.title.x = element_text(size = 16),
  legend.text = element_text(size = 14)
)

avg_comparisons(
  model = mod_sr_n_pauses,
  variables = "phase",
  by = "language"
) |>
posterior_draws() |>
ggplot() +
aes(x = draw, y = language) +
geom_rect(
  inherit.aes = F,
  data = tibble(xmin = -10, xmax = 10),
  aes(xmin = xmin, xmax = xmax, ymin = -Inf, ymax = Inf),
  fill = my_col(b = 0.5, n = 1, a = 0.2), color = "white",
) +
geom_vline(xintercept = 0, lty = 3) +
stat_halfeye(
  aes(alpha = after_stat(abs(x) < 10)),
  slab_fill = my_col(b = 0.5, n = 1), slab_color = "white",
  show.legend = F, pch = 21, point_fill = "white"
) +
scale_alpha_manual(values = c(1, 0.4)) +
scale_y_discrete(position = "right") +
labs(x = "Average marginal estimate\nPost - Pre", y = NULL) +
theme(
  axis.text.y.right = element_text(angle = -90, hjust = 0.5, size = 16),
  axis.text.x = element_text(size = 14),
  axis.title.x = element_text(size = 16)
)

```



- (a) Number of pauses produced as a function of lan- (b) Average marginal estimate of the difference between 'pre' and 'post' pauses for each language.

Figure 2: Pauses produced

```
bind_rows(
  n_pauses_post |>
    group_by(language, phase) |>
    median_hdi(value) |>
    slice(-4) |>
    mutate(across(value:.upper, \(x) specify_decimal(x, k = 2))) |>
    transmute(
      Language = glue("{language}: {phase}"),
      Estimate = value,
      HDI = glue("[{.lower}, {.upper}]")
    ),

  avg_comparisons(
    model = mod_sr_n_pauses,
    variables = "phase",
    by = "language"
  ) |>
  as_tibble() |>
  mutate(
    contrast = str_remove_all(contrast, "mean\\(|\\|\\|)"),
    contrast = str_to_title(contrast)
  ) |>
  mutate(across(estimate:conf.high, \(x) specify_decimal(x, k = 2))) |>
  transmute(
    Language = glue("{language}: {contrast}"),
    Estimate = estimate,
```


Table 4: Number of pauses

Language	Estimate	HDI
English: Pre	3.79	[1.78, 6.80]
English: Post	17.23	[7.57, 31.66]
Spanish: Pre	14.62	[3.64, 32.20]
Spanish: Post	71.02	[38.46, 115.61]
Average marginal estimate		
English: Post - Pre	21.73	[19.74, 23.91]
Spanish: Post - Pre	59.84	[55.62, 64.04]

```

    HDI = glue("[{conf.low}, {conf.high}]")
  )
) |>
tt(width = 0.75) |>
style_tt(j = 2:3, align = "r") |>
group_tt(i = list("Average marginal estimate" = 5)) |>
style_tt(i = 0, line = "t", line_color = "black", line_width = 0.1) |>
style_tt(i = 4, line = "b", line_color = "black", line_width = 0.05) |>
style_tt(i = 7, line = "b", line_color = "black", line_width = 0.1)

```

Articulation rate

```

get_prior(
  formula = bf_z,
  family = gaussian(),
  data = filter(dat_z, metric == "ar")
) |>
select(prior, class, coef) |>
knitr::kable()

```

prior	class	coef
	b	

prior	class	coef
lkj(1)	b	phasepost:languageEnglish
	b	phasepost:languageSpanish
	b	phasepre:languageEnglish
	b	phasepre:languageSpanish
	cor	
student_t(3, 0, 2.5)	cor	
	sd	
	sd	
	sd	Intercept
	sd	phasepost:languageEnglish
student_t(3, 0, 2.5)	sd	phasepost:languageSpanish
	sd	phasepre:languageEnglish
	sd	phasepre:languageSpanish
	sigma	

```
ar_prior <- c(
  prior(normal(0, 2.5), class = "b"),
  prior(lkj(1), class = "cor"),
  prior(exponential(2), class = "sd"),
  prior(exponential(2), class = "sigma")
)
```

```
mod_sr_ar <- brm(
  formula = bf_z,
  family = gaussian(),
  prior = ar_prior,
  sample_prior = "no",
  chains = 4, iter = 2000, warmup = 1000,
  cores = 4, threads = threading(2),
  backend = "cmdstanr",
  data = filter(dat_z, metric == "ar"),
  file = here("models", "mod_sr_ar")
)
```

```
ar_post <- as_tibble(mod_sr_ar) |>
  transmute(
    English_pre = `b_phasepre:languageEnglish`,
    English_post = `b_phasepost:languageEnglish`,
    Spanish_pre = `b_phasepre:languageSpanish`,
    Spanish_post = `b_phasepost:languageSpanish`
  )
```

```

) |>
pivot_longer(cols = everything()) |>
separate(name, into = c("language", "phase"), sep = "_") |>
mutate(
  phase = str_to_title(phase),
  phase = fct_relevel(phase, "Pre")
)

ar_post |>
ggplot() +
aes(y = language, x = value, group = phase) +
geom_point(
  data = filter(dat_z, metric == "ar") |>
    mutate(phase = str_to_title(phase), phase = fct_relevel(phase, "Pre")),
  mapping = aes(y = language, x = val_z, fill = phase),
  position = ggpp::position_dodgenudge(
    x = 0, direction = "split", width = 0.5
  ),
  pch = 21, alpha = 0.4, size = 3, color = "white", stroke = 1
) +
stat_halfeye(
  aes(fill = phase),
  position = ggpp::position_dodgenudge(
    y = 0.06, direction = "split", width = 0.5),
  pch = 21, point_fill = "white", show.legend = F
) +
scale_fill_viridis_d(name = NULL, option = "D", begin = 0.4, end = 0.8) +
scale_color_viridis_d(name = NULL, option = "D", begin = 0.4, end = 0.8) +
labs(y = NULL, x = "Articulation rate\n") +
guides(fill = guide_legend(override.aes = list(alpha = 1, size = 3))) +
theme(
  legend.position = "inside", legend.justification.inside = c(1, 0),
  legend.background = element_blank(),
  axis.text.y = element_text(angle = 90, hjust = 0.5, size = 16),
  axis.text.x = element_text(size = 14),
  axis.title.x = element_text(size = 16),
  legend.text = element_text(size = 14)
)

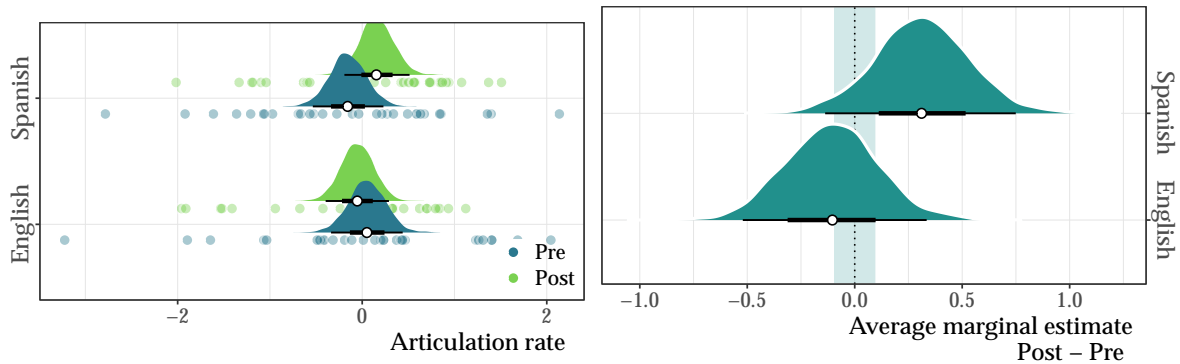
avg_comparisons(
  model = mod_sr_ar,
  variables = "phase",

```

```

by = "language"
) |>
posterior_draws() |>
ggplot() +
aes(x = draw, y = language) +
geom_rect(
  inherit.aes = F,
  data = tibble(xmin = -0.1, xmax = 0.1),
  aes(xmin = xmin, xmax = xmax, ymin = -Inf, ymax = Inf),
  fill = my_col(b = 0.5, n = 1, a = 0.2), color = "white",
) +
geom_vline(xintercept = 0, lty = 3) +
stat_halfeye(
  aes(alpha = after_stat(abs(x) < 10)),
  slab_fill = my_col(b = 0.5, n = 1), slab_color = "white",
  show.legend = F, pch = 21, point_fill = "white"
) +
scale_alpha_manual(values = c(1, 0.4)) +
scale_y_discrete(position = "right") +
labs(x = "Average marginal estimate\nPost - Pre", y = NULL) +
theme(
  axis.text.y.right = element_text(angle = -90, hjust = 0.5, size = 16),
  axis.text.x = element_text(size = 14),
  axis.title.x = element_text(size = 16)
)

```



- (a) Average articulation rate as a function of language (English, Spanish) and phase (pre, post). (b) Average marginal estimate of the difference between 'pre' and 'post' articulation rate for each language.

Figure 3: Articulation rate

```

bind_rows(
  ar_post |>
    group_by(language, phase) |>
    median_hdi(value) |>
    mutate(across(value:.upper, \(x) specify_decimal(x, k = 2))) |>
    transmute(
      Language = glue("{language}: {phase}"),
      Estimate = value,
      HDI = glue("[{.lower}, {.upper}]")
    ),

  avg_comparisons(
    model = mod_sr_ar,
    variables = "phase",
    by = "language"
  ) |>
  as_tibble() |>
  mutate(
    contrast = str_remove_all(contrast, "mean\\(|\\|\\|"),
    contrast = str_to_title(contrast)
  ) |>
  mutate(across(estimate:conf.high, \(x) specify_decimal(x, k = 2))) |>
  transmute(
    Language = glue("{language}: {contrast}"),
    Estimate = estimate,
    HDI = glue("[{conf.low}, {conf.high}]")
  )
) |>
tt(width = 0.75) |>
style_tt(j = 2:3, align = "r") |>
group_tt(i = list("Average marginal estimate" = 5)) |>
style_tt(i = 0, line = "t", line_color = "black", line_width = 0.1) |>
style_tt(i = 4, line = "b", line_color = "black", line_width = 0.05) |>
style_tt(i = 7, line = "b", line_color = "black", line_width = 0.1)

```

Average syllable duration

```

get_prior(
  formula = bf_z,

```

Table 6: Articulation rate

Language	Estimate	HDI
English: Pre	0.05	[-0.34, 0.44]
English: Post	-0.05	[-0.39, 0.29]
Spanish: Pre	-0.16	[-0.53, 0.23]
Spanish: Post	0.15	[-0.19, 0.52]
Average marginal estimate		
English: Post - Pre	-0.10	[-0.52, 0.33]
Spanish: Post - Pre	0.31	[-0.14, 0.75]

```

family = gaussian(),
data = filter(dat_z, metric == "asd")
) |>
select(prior, class, coef) |>
knitr::kable()

```

prior	class	coef
	b	
	b	phasepost:languageEnglish
	b	phasepost:languageSpanish
	b	phasepre:languageEnglish
	b	phasepre:languageSpanish
lkj(1)	cor	
	cor	
student_t(3, 0, 2.5)	sd	
	sd	
	sd	Intercept
	sd	phasepost:languageEnglish
	sd	phasepost:languageSpanish
	sd	phasepre:languageEnglish
	sd	phasepre:languageSpanish
student_t(3, 0, 2.5)	sigma	

```
asd_prior <- c(
  prior(normal(0, 2.5), class = "b"),
  prior(lkj(1), class = "cor"),
  prior(exponential(2), class = "sd"),
  prior(exponential(2), class = "sigma")
)
```

```
mod_sr_asd <- brm(
  formula = bf_z,
  family = gaussian(),
  prior = asd_prior,
  sample_prior = "no",
  chains = 4, iter = 2000, warmup = 1000,
  cores = 4, threads = threading(2),
  backend = "cmdstanr",
  control = list(adapt_delta = 0.99),
  data = filter(dat_z, metric == "asd"),
  file = here("models", "mod_sr_asd")
)
```

```
asd_post <- as_tibble(mod_sr_asd) |>
  transmute(
    English_pre = `b_phasepre:languageEnglish`,
    English_post = `b_phasepost:languageEnglish`,
    Spanish_pre = `b_phasepre:languageSpanish`,
    Spanish_post = `b_phasepost:languageSpanish`
  ) |>
  pivot_longer(cols = everything()) |>
  separate(name, into = c("language", "phase"), sep = "_") |>
  mutate(
    phase = str_to_title(phase),
    phase = fct_relevel(phase, "Pre")
  )
```

```
asd_post |>
  ggplot() +
  aes(y = language, x = value, group = phase) +
  geom_point(
    data = filter(dat_z, metric == "asd") |>
      mutate(phase = str_to_title(phase), phase = fct_relevel(phase, "Pre")),
    mapping = aes(y = language, x = val_z, fill = phase),
    position = ggpp::position_dodgenudge(
```

```

      x = 0, direction = "split", width = 0.5
    ),
    pch = 21, alpha = 0.4, size = 3, color = "white", stroke = 1
  ) +
  stat_halfeye(
    aes(fill = phase),
    position = ggpp::position_dodgenudge(
      y = 0.06, direction = "split", width = 0.5),
    pch = 21, point_fill = "white", show.legend = F
  ) +
  scale_fill_viridis_d(name = NULL, option = "D", begin = 0.4, end = 0.8) +
  scale_color_viridis_d(name = NULL, option = "D", begin = 0.4, end = 0.8) +
  labs(y = NULL, x = "Average Syllable Duration\n") +
  guides(fill = guide_legend(override.aes = list(alpha = 1, size = 3))) +
  theme(
    legend.position = "inside", legend.justification.inside = c(1, 0),
    legend.background = element_blank(),
    axis.text.y = element_text(angle = 90, hjust = 0.5, size = 16),
    axis.text.x = element_text(size = 14),
    axis.title.x = element_text(size = 16),
    legend.text = element_text(size = 14)
  )

avg_comparisons(
  model = mod_sr_asd,
  variables = "phase",
  by = "language"
) |>
posterior_draws() |>
ggplot() +
aes(x = draw, y = language) +
geom_rect(
  inherit.aes = F,
  data = tibble(xmin = -0.1, xmax = 0.1),
  aes(xmin = xmin, xmax = xmax, ymin = -Inf, ymax = Inf),
  fill = my_col(b = 0.5, n = 1, a = 0.2), color = "white",
) +
geom_vline(xintercept = 0, lty = 3) +
stat_halfeye(
  aes(alpha = after_stat(abs(x) < 10)),
  slab_fill = my_col(b = 0.5, n = 1), slab_color = "white",
  show.legend = F, pch = 21, point_fill = "white"
)

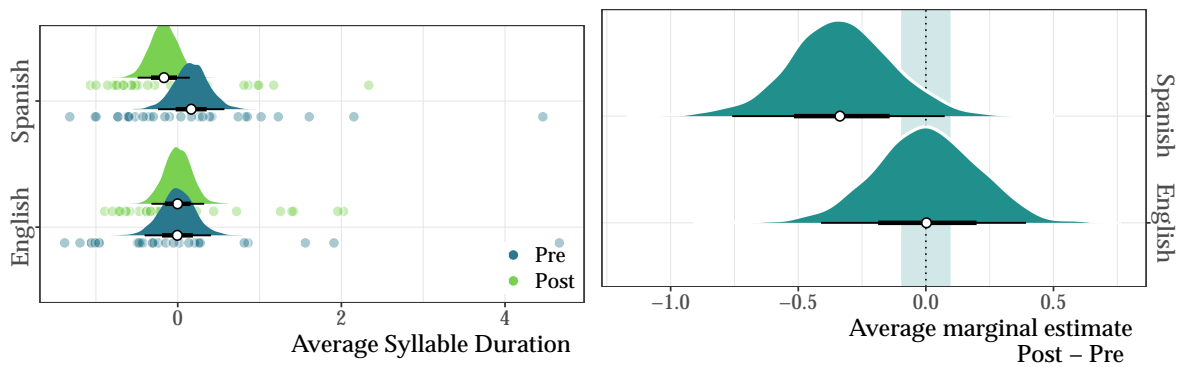
```



```

) +
scale_alpha_manual(values = c(1, 0.4)) +
scale_y_discrete(position = "right") +
labs(x = "Average marginal estimate\nPost - Pre", y = NULL) +
theme(
  axis.text.y.right = element_text(angle = -90, hjust = 0.5, size = 16),
  axis.text.x = element_text(size = 14),
  axis.title.x = element_text(size = 16)
)

```



- (a) Average syllable duration as a function of language (English, Spanish) and phase (pre, post). (b) Average marginal estimate of the difference between 'pre' and 'post' articulation rate for each language.

Figure 4: Average syllable duration

```

bind_rows(
  asd_post |>
    group_by(language, phase) |>
    median_hdi(value) |>
    mutate(across(value:.upper, \(x) specify_decimal(x, k = 2))) |>
    transmute(
      Language = glue("{language}: {phase}"),
      Estimate = value,
      HDI = glue("[{.lower}, {.upper}]")
    ),
  avg_comparisons(
    model = mod_sr_asd,
    variables = "phase",
    by = "language"
  )
)

```

Table 8: Articulation rate

Language	Estimate	HDI
English: Pre	-0.01	[-0.41, 0.40]
English: Post	0.00	[-0.34, 0.30]
Spanish: Pre	0.16	[-0.24, 0.57]
Spanish: Post	-0.17	[-0.50, 0.14]
Average marginal estimate		
English: Post - Pre	0.00	[-0.41, 0.39]
Spanish: Post - Pre	-0.34	[-0.76, 0.07]

```

) |>
  as_tibble() |>
  mutate(
    contrast = str_remove_all(contrast, "mean\\(|\\|\\|)"),
    contrast = str_to_title(contrast)
  ) |>
  mutate(across(estimate:conf.high, \(x) specify_decimal(x, k = 2))) |>
  transmute(
    Language = glue("{language}: {contrast}"),
    Estimate = estimate,
    HDI = glue("[{conf.low}, {conf.high}]")
  )
) |>
tt(width = 0.75) |>
style_tt(j = 2:3, align = "r") |>
group_tt(i = list("Average marginal estimate" = 5)) |>
style_tt(i = 0, line = "t", line_color = "black", line_width = 0.1) |>
style_tt(i = 4, line = "b", line_color = "black", line_width = 0.05) |>
style_tt(i = 7, line = "b", line_color = "black", line_width = 0.1)

```

Discussion

Tentative conclusions

- After spending 7 weeks using Spanish exclusively, the L2 learners L1 (English) was not affected with regard to fluency metrics
- Our initial findings lend support to the L2LP model

Next steps

- Analyze entire corpus (n = 400 interviews)
- Extend analysis to segments (e.g., stops, vowels, laterals)

References

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- . 2013. “A Novelty Effect in Phonetic Drift of the Native Language.” *Journal of Phonetics* 41 (6): 520–33.
- Flege, James Emil, and Ocke-Schwen Bohn. 2021. “The Revised Speech Learning Model (SLM-r).” In *Second Language Speech Learning: Theoretical and Empirical Progress*, edited by Rattree Wayland, 3–83. Cambridge University Press. <https://doi.org/10.1017/9781108886901.002>.
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