| Paper | Topic | Paradigm | Measurement | Block Design | Stimuli & other aspects | Prediction | Comments |
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| Wade (2022) | Linguistic Convergence/  Dialect adaptation/Speech production | Word elicitation prompted by a written hint and spoken hint. | Mean change in measurement of vowel /ai/  Qualitative change? YES | 3 phases of elicitation of vowel /ai/.  T-ET-T  30 trials per phase = 90 trials | Phase 1: Written hint and participant says word (prior production).  Phase 2: Spoken hint (Exposure) either in Midland or Southern accent (between participants). Participant says word.  Phase 3: Written hint to investigate whether convergence is maintained  Participant vowel productions are measured for the realisation of the offglide along front diagonal of vowel space.  Analysis divided listeners’ by their region of origin (Southern or non-Southern)  The group that heard the hints delivered in a Southern voice shifted their /ai/ productions to be more Southern-like.  Interaction between listener origin, experiment phase and talkder dialect– Southern listeners shifted more than non-southerners. In phase 3 of Southern dialect condition, both Southeners and non-southeners show some but not full return to their baseline productions. | The group that receives hints in a Southern voice will have weaker glides in Phase 2 (lower measurements of glide compared to the group that hears it in a Midland voice). | Although this study is about production it goes to show that listeners maintain speaker models in their representation.  Listeners did not get any evidence of the southern /ai/ but both Southern and non-Southern listeners shifted their /ai/ productions towards what they believe were the talker’s origins.  This provides some support for the argument that listeners select from speaker models held in memory and behave accordingly.  Applied to our discussion, one could say listeners match the exposure talker to a best-fit model in their representation and hold quite strongly to it. |
| Escudero & Williams (2014) | L2 learning of vowel contrast | L2 Distributional Learning of vowels. Longitudinal study | % correct identification in XAB task.  Qualitative change? Yes | T-E-T (1st session)  T-E-T (2nd session; 6 mths from 1st session)  T (3rd session 12 mths from 1st session)  Pre-test: 80 trials  Exposure: 128 trials  Test: 80 trials  Exposure type (between participants)  1: Bimodal narrow  2: Bimodal enhanced  3: Music (control) | Exposure tokens were synthesised, duration held constant.  Test tokens (X token) are natural stimuli from 10 talkers, M & F of a Dutch corpus, with F1, F2 and *durational* cues.  A & B tokens are synthesised tokens with fixed at mean F1 and F2 values for each category. Duration held constant.  Post-test compared to pre-test in 1st and 2nd sessions to assess ST learning.  Pre-tests compared between sessions to assess LT learning. | Bimodal enhanced group expected to show greater improvement than bimodal narrow group.  Improvements to be seen in the ST (6 months) and LT (12 months)  While they found some evidence of LT training effects, it was only for the narrow bimodal group and not for the bimodal enhanced. This raises questions because they started from the position that wide variance training was superior to narrow variance training. | This study set up a pre-test solely for comparison of accuracy between pre- and post-exposure. The difference from our approach is there isn’t any evaluation of where learners’ beliefs about the distribution lay and how this changed after each exposure. In my reading, the study says very little about participants’ prior beliefs because there isn’t an estimation of their categorization boundary along the relavant cue dimensions. Their concern was with improvement in categorisation. We are systematically tracking the shifts in perception as a consequence of their hypothesised learning of the phonetic distributions of the talker. In this study the test tokens are not plotted against training tokens to relate how the location of the distribution during exposure affects test. |
| Escudero et al., (2011)  N.B.  Both R2 and R3 cited this paper | L2 learning (vowel contrast) | L2 Distributional learning over short exposure. | % correct identification in XAB task.  Qualitative analysis? Yes | T-E-T  Exposure type (between participants)  1: Bimodal narrow  2: Bimodal enhanced  3: Music (control) | Pre-test: 80 trials  Exposure: 128 trials  Post-test: 80 trials  Exposure tokens were synthesised, duration held constant.  Test tokens (X token) are natural stimuli from 10 talkers, M & F of a Dutch corpus, with F1, F2 and *durational* cues.  A & B tokens are synthesised tokens with fixed at mean F1 and F2 values for each category. Duration held constant. | Bimodal enhanced group expected to show greater improvement than narrow variance group. | My comments on this paper are the same as Escudero & Williams (2014) since they are essentially the same design but with different time frames.  I think a key difference between our testing of DL hypothesis and these L2 DL studies is in the specificity of the predictions. In these L2 studies they don’t seem to strictly adhere to the statistical learning principle. If learners are tracking statistics then the statistics of the cues before, during, and after exposure should matter and be measured. They hold to a general idea that exposure to wide or narrow distributions (I presume located within reasonable range) is what affects post-perceptual learning. So it doesn’t seem to matter so much where the test tokens are located relative to the exposure tokens.  A deeper analyses of their results would be interesting though. |
| Kraljic & Samuel (2007) | Perceptual recalibration/Learning talker models/  Generalisation of perceptual learning | Lexically guided perceptual learning of /s - sh/ and /d - t/ across different talkers. | Comparison categorisation of test stimuli by talker  Qualitative analysis? Yes | Experiment 1: E – E – T– T  Exposures were of 2 talkers crossed with ambiguous /d/ and ambigous /t/ items.  Tests were given in both voices and blocked by voice.  Experiment 2: E – E – T– T  Items were shifted /s/ or /sh/  Exposure: 10 shifted /d/ 10 clear /t/ from 1st talker; 10 shifted /t/ 10 clear /d/ 2nd talker = 40 critical trials  Test: 120 trials (6 test locations x 2 talkers x 10 randomisations) | Listeners exposed to 2 talkers, one with shifted /d/ and the other with shifted /t/ in lexical contexts that bias their perceptions in opposite directions. Tested on d-t continuum with voices from both exposure talkers. Same design in experiment 2 but with shifted /s/ or shifted /sh/. | Exposure to shifted fricatives (experiment 2) is expected to result in perceptual learning that is speaker-specific – listeners will categorise test continuum of each talker according to the bias they were exposed to. | This study does not compare listeners’ shift in categorisation before and after exposure.  R2 noted this paper for the number of trials (10) required for perceptual learning.  I think R2 wants us to note that other studies have shown the small number of trials for adaptation. They say “several studies on the amount of exposure needed for PL to take place are not cited”. We do discuss this and cite more recent work like Cummings & Theodore, which I believe is more specified than those before it. Besides that. I think this paper is testing a different question from us. |
| Poellmann et al., 2011 | Perceptual recalibration | Lexically guided perceptual learning of /s/ and /f/. Visual world paradigm | Perceptual change is assessed by estimating an average learning function over 2 blocks for each group (s-biased or f-biased). This is derived by subtracting the distance of fixations to the target from the distance of fixations to the competitor in each block and averaging them over 2 blocks | E-T (within each block)  Exposure:  40 shifted items (20 embedded within temporary min pairs, 20 clear items  Test: 20 items | Investigates when recalibration emerges. Also asks if learning is gradual or step-wise.  The experiment exposes participants to shifted s or f while tracking their eye movements. Stimuli were delivered in blocks, with each block containing typical LGPL exposure trials (ambiguous s/f followed by clear s/f), test trials, less typical LGPL exposure trials (s/f embedded in temporary min pairs like gis/ftig – gis/fter ) and fillers. Total of 12 trials per block and 20 blocks. The order of blocks was the same for every participant.  They found that in the first half both groups preferred looking at the s-item indicating that the stimuli was more s-sounding. The s-biased group always performed well by correctly looking at the target even in the earliest blocks. The f-biased group showed a sudden change in learning during block 11-12 and block 17-18 where they had a net preference in looks to the target. In most trials the f-biased group had a net preference for the competitor. | If perceptual recalibration is affected by amount of exposure, a gradual increase in the learning function would be observed as the listener receives more exposure of the shifted sound. | This is an IcPhs proceedings paper which wasn’t published elsewhere.  This design is quite different from typical LGPL in that it has a test trial almost immediately after an exposure trial so that they are able to track the changes in perception trial-by-trial.  I think this study is interesting and relevant to us because it aimed to track block-to-block changes in learning. Their results did not provide strong evidence of rapid learning (they were trying to replicate the 10 exposure trials reported in Kraljic & Samuel 2007). While they report that perceptual learning is step-wise rather than gradual, I think their results can be challenged. Again, I think this study’s shortcoming is that they do not locate the distribution of their stimuli nor relate the cue measurements of the exposure stimuli to the test stimuli (or to the expectations of listeners before hearing the stimuli). This was the case with most LGPL studies in the earlier days and it was probably not until Drouin et al 2016 that they began to do that.  We could cite this study as one early attempt to detect the gradation of perceptual learning. |
| Witteman et al., 2013 | Accent adaptation | Cross-modal priming of German-accented Dutch | Reaction times to words and non-words. | Experiment 1: Only one phase  T  Experiment 2:  E-T  Experiment 3:  E-T  All experiments (test): 48 critical items & 96 fillers  Experiment 2: 4 mins exposure to German accented Dutch.  Experiment 3: 4 mins exposure to German accented Dutch but tested on a different talker (same talker as Exp 1 & 2). | Dutch listeners with greater or lesser experience with German accents respond to primes of strongly, medium, and weakly-accented primes.  Experiment 1 tested 2 groups, 1 with experience in German accented Dutch and one without.  Experiment 2 tested a naïve group after ST exposure to German accented Dutch.  Experiment 3 design is similar to exp 2 but tested listeners’ ability to generalise learning an accent from 1 talker to another. | Extensive experience with an accent facilitates recognition of words by that accent. | This study discusses how prior experience/exposure affects how quickly one adapts to accented speech.  They note the speaker-dependent nature of ST adaptation because naïve listeners exposed to a German accented talker did not give much advantage in a later test phase which had a different talker.  However, this conclusion contradicts the finding that experienced listeners showed stronger priming. But it could be argued that generalisation of accent learning happens over longer periods.  I think this study is distantly related to our paper because of its research questions. R2 mentioned this paper as an e.g. of studies that looked into prior knowledge, which they criticise us for not acknowledging.  That’s similar but we are estimating prior perception and tracking the direction of change due to recent exposure. This paper recognises the role prior experience plays and divides its participants into groups by experience. It is not measuring the degree or direction of adaptation. We can cite/acknowledge that people have thought of accounting for prior experience before but they don’t usually try to estimate the representation in terms of cue distributions. |
| Zhang & Holt 2018  (experiment 1) | Adaptation to manipulated VOT-F0 correlations.  How do changing statistical relationships between cues affect perception. | Holt’s dimension based stat. learning | At pre-test: Proportion of voiceless (“pier”) responses at each VOT-F0 location  Post-exposure test: Proportion of voiceless responses at the 2 test locations. | T - E+T - E+T -E+T  (E+T = test randomised with exposure)  Pre-test trials: 120  Exposure trials: 100 per block = 300 trials  Test trials: 20 (2 test locations repeated 10x) per block = 60 total test trials | Listeners given 3 blocks of exposure where VOT either correlated with F0 in the expected direction (canonical) or in the reverse direction. The order was canonical-reverse-canonical. F0 ranges were manipulated between participants to be either relatively higher (high F0 condition) or relatively lower (low F0 condition).  Prior to exposure listeners in both the high F0 and low F0 group were subjected to a pre-test to check how they categorised the VOT-F0 continuua. (120 total trials).  Both groups were exposed to a mid-level F0 value (210 Hz). This mid-level F0 value was taken as the low F0 (coupled with short VOTs) for the high F0 condition and taken as the high F0 value (coupled with long VOTs) in the low F0 condition.  Test stimuli were placed in one VOT location –10ms coupled with either mid-level F0 or high F0 in the high condition or with mid-level and low F0 for the low condition. | Perception of F0 to voicing is affected by recent exposure and its placement relative to the F0 value of the competing category.  Listeners adapt their interpretation of F0 values depending on how it correlated with VOT during exposure and depending on the range of F0 values they heard during exposure. | Categorisation of the ambiguous stimuli showed that the respective groups adapted their perception relative to the F0 range that they were exposed to.  Crucially, in the ambiguous test stimuli, mid-level F0 was categorised more as /b/ in the high F0 group and more as /p/ in the low F0 group. This suggests that listeners normalised the F0 to reflect the exposure distribution. I thought this was the more interesting result of the experiment.  The pre-testing was done to determine how F0 affected the categorisation of stimuli in the absence of VOT or correlational statistics.  Listeners in respective groups were given two uniform VOT continuaa paired with the 2 F0 levels. This could be taken as their prior expectations of the stimuli.  The results show that listeners can change the way they categorise ambiguous stimuli according to correlations of recent exposure.  Because there isn’t much distributional manipulation other than the correlation of VOT and F0, this study is quite different to ours in design.  They do have tests at each block to track changes but as the average proportion of voiceless categorizations after 100 trials and only at 2 locations. |
| Logan et al., 1991 | L2 learning of /r/ and /l/; effects of exposure to wide variety of talkers and contexts | Pre-test,  training with feedback, post-test.  2AFC task | % of correct responses to /r/ and /l/ words.  Qualitative measurement | T-E-T  Pre-test: 32 trials  (3 out of 6 participants were given the test twice with a 2-week break in between to determine if doing tests alone led to improvements.)  Training: 272 trials per session with feedback. Total of 15 sessions (x5 talkers). Total of 4,080 trials over 3 weeks.  Post-test = 32 trials. | In the pre and post-test listeners heard minimal pair /r-l/ words various phonetic contexts.  In training listeners were given /r/ and /l/ tokens in various phonetic contexts and by different talkers.  For the 3 participants who received pre-test twice, no difference in performance was found between the 2 sessions.  Overall mean accuracy improved from 78.1% in pre-test to 85.9% in post-test.  They also found improvements in accuracy from week to week during training but the gains in week 3 were smaller than the gain in week 2 and not statistically significant.  Some phonetic contexts showed greater improvements than others (initial clusters, and intervocalic). Initial /r-l/ and final /r-l/ words showed smaller improvements. | Listeners would improve their identification of /r/ and /l/ after training (higher % of correct answers). | This study’s pre- and post-test were set up to track changes in listener identification performance.  There is some analysis of week-to-week changes in listener accuracy during training sessions which is similar to our tracking of block-to-block changes.  The time frame of this analysis is much longer and with many more trials in between each week, what could be relevant for us to cite is that the incremental gains diminished in the final week of training.  One other difference is that talkers are changed after cycling through three sessions (272 trials x3) per talker. |
| Eisner & McQueen 2006 |  |  |  |  |  |  |  |
| Anderson 1982 | Theory about the use and development of declarative and procedural knowledge. |  |  |  |  |  |  |
| Gauthier et al., 2007 | Statistical Learning of Mandarin tones |  |  |  |  |  |  |
| Goudbeek et al., 2008 | Distributional learning of multi-dimensional stimuli (Dutch vowels that differ in duration, formant frequency or both) with or without supervision. | Distributional exposure with or without feedback.  Categorisation task | % correct identification and d’ score in categorisation. Logistic regression to compare cue reliance before and after exposure | T-E-E-T  Pre- & post-test: 196 trials each with test items located between the means of the 2 vowel categories  Exposure: 448 trials over 2 blocks (224 trials per block) Short rest period given between sessions. | Experiment 1:  Spanish L1 learners; feedback given during exposure (within participants). Duration and Frequency relevant cues manipulated between participants.  Performance in pre and post-test was assssed by logistic regression (I am unfamiliar with the way they applied the logistic regression. They did one for each participant and averaged the estimates.) There was an overall preference for the relevant dimension over the irrelevant dimension. Changes in % correct and d’ between exposure phases were also assessed. In the duration-relevant condition, listeners increased their % correct in the 2nd exposure phase. Improvement observed in formant-relevant conditions but difference was not significant.  Experiment 2: Same as experiment 1 with L1 spanish learners but no feedback given during exposure. Without feedback and only arbitrary labelling of the 2 categories (A vs B) there is no a priori correct answer. For each listener, the category most associated with response A was defined as category A. The chance level performance was adjusted based on a binomial distribution of 224 trials. (I’m not very clear on this small detail, section 3.2.1 for clarification if needed)  Without feedback performance in terms of d’ did not improve between phases. In terms of % correct, the bars don’t look very different from experiment 1. Main effect of dimension training (formant vs duration) was significant. Those in the formant-relevant condition had much higher than chance scores overall.  Logistic regression analysis or pre- and post-test categorisation did not show significant changes in preference for relevant over irrelevant dimensions but instead depended more on Formant dimensions overall.  Experiment 3: Exactly the same setup as experiment 1 but only with one condition (duration-relevant training), L1 AE participants and half the number (10 vs 20). AE listeners during exposure, showed significantly more % correct responses than Spanish learners (exp 1). Between exposure phases the gains in learning was not significant even for AE listeners. Logistic regression analysis confirmed that AEs were better able at making use of duration for learning.  Experiment 4:  Same format as experiment 1 but with 18 AE listeners. Both duration and formant dimensions covaried. Feedback was given. Accuracy and d’ measures showed no significant learning between exposure phases. Overall accuracy for this AE group was poorer than the AE group in experiment 3. Most participants made use of a single dimension (formants) to discriminate categories. Logistic regression analysis suggest that learners could make use of both dimensions during the exposure phases eventhough overall performance was poorer than the previous one-dimensional experiment. However during the maintenance phases (without feedback) they reverted to relying on just one dimension. | Feedback is expected to facilitate better distributional learning.  Prior expectations (as determined by L1 categories) affect listeners’ preference for cues as well as ability to learn the categories. | This study is more closely related to ours.  They were very systematic in stimuli construction. They had set means and SDs for each category’s distribution and they sampled their stimuli from each distribution.  Their presentation of the 2 category distributions were a bit different to ours and more like Holt’s dimension based stat learning paradigm. For the irrelevant dimension, the 2 categories completely overlapped and for the relevant dimensions listeners only had to learn 2 mean values. There is no/ very little gradation along the relevant dimension (see Table 1 pg. 113 for statistics).  For the covarying stimuli, fig 1 on pg. 111  While they took care to place the means of the vowels according to reported means of prior studies, they did not discuss how they set the variances other than noting it was defined by “just noticeable differences”. But this may be less important since we can assume the participants had very little to no prior knowledge of the statistics. And they were not tasked to categorise by vowel name  An interesting early study of DL for speech perception. There is some analysis of incremental learning but not as fine-grained as our study.  They do not estimate prior boundaries of learners. Their participants are practically naïve to Dutch. This is a cross-linguistic analysis which is more challenging in its own way. There isn’t a more specified direction of their predictions.  Another difference is that they studied this question over many more trials and their discussion emphasised the effect of feedback which I’m not convinced made a huge amount of difference (but I could be interpreting it wrongly, check out section 3.2 for specifics). |
| Goudbeek et al., 2009 | Multidimensional distributional learning | Distributional exposure with or without feedback.  Categorisation task | % correct identification and d’ score in categorisation. Logistic regression to compare cue reliance before and after exposure. | E-E-T  Exposure: 448 trials (224 x 2 blocks with a brief rest period in between)  Test: 196 trials (49 stimuli x 4 blocks) | Stimuli are sampled from gaussians with specified means and SDs (table 1 p. 1919). In uni-dimensional relevant conditions, r = 0; multi-dimensional (covarying) conditions, r = -1  Experiment 1:  N = 36; 3 conditions – Duration-relevant, frequency-relevant, multi-dimensional (covarying cues). Test stimuli were a grid of equidistantly spaced points. Feedback given after every exposure trial.  Experiment 1B: N = 12,  Exposure – covarying cues – 448 trials.  Test stimuli were 224 trials (equivalent to 1 block during exposure) with both cues perfectly covarying.  Feedback given after every exposure trial.  Experiment 2:  N = 36; 3 conditions – Duration-relevant; Frequency-relevant; Multi-dimensional (covarying cues). Exposure and test same as Experiment 1.  No feedback given.  Task: 2AFC assignment to either A or B. Performance measured by % correct and d’ scores. Logistic regression for analysis of cue dependence. | Multi-dimensional learning is harder than uni-dimensional. Main effect of dimension. Test performance in multi-dimensional will be poorer than uni-dimensional.  Category learning will be facilitated by feedback. Main effect of feedback. Conditions with feedback will show better performance than condition without. | This study design is very similar to that above but with stimuli that is speech-like but not meant to represent any category of any language.  There was no pre-test.  The distributions were less ecologically valid than our distributional design. For e.g. in the conditions where only one dimensional learning was required, the relevant dimension was made up of only 2 mean values. For the conditions where both cue dimensions were relevant, the correlation was perfect (-1). Variances were equal. |
| Guenther & Gjaja 1996 |  |  |  |  |  |  |  |
| Heathcote et al., 2000 |  |  |  |  |  |  |  |
| Logan 1988 |  |  |  |  |  |  |  |
| Maye & Gerken, 2000 | Acquisition of speech categories through distributional learning | DL; bimodal vs. unimodal distribution | Proportion of correct discrimination during test phase.  Participants respond “SAME” or “DIFFERENT” to pairs of /da-ta/ test stimuli.  Results are measured by the proportion of correct “DIFFERENT” responses. | E-T  Exposure: 384 trials (including fillers)  Test: Did not report number of trials | Pairs of /d-t/ syllables along an 8 step continuum.  Participants given either bimodal or unimodal exposure to stimuli.  Stimuli end points (step1 and step 8) heard only once by both groups. These same stimuli were used as contrasting (different) test pairs. | Bimodally trained group expected to score better with a higher proportion of correct “DIFFERENT” responses than the unimodally trained group. | Early DL study that inspired a lot of L2 follow ups. Should be cited.  Study designs have been improved and modified since (Clayards et al 2008 etc…) |
| Maye et al, 2003 |  |  |  |  |  |  |  |
| McMurray et al., 2009 |  |  |  |  |  |  |  |
| McMurray et al., 2009b |  |  |  |  |  |  |  |
| Newell & Rosenbloom 1981 |  |  |  |  |  |  |  |
| Rescorla 1988 |  |  |  |  |  |  |  |
| Palmer, 1997 |  |  |  |  |  |  |  |
| Toscano & McMurray 2010 |  |  |  |  |  |  |  |