Published in final edited form as:

J Commun Disord. 2011 ; 44(5): 564–567. doi:10.1016/j.jcomdis.2011.04.003.

Predictors of spoken language learning

Patrick C. M. Wong^{a,b,*} and Marc Ettlinger^a

^a Department of Communication Sciences & Disorders, School of Communication, Northwestern University, 2240 Campus Drive, Evanston, IL 60208, USA

^b Department of Otolaryngology - Head and Neck Surgery, Feinberg School of Medicine, Northwestern University, 676 N St Clair, Suite 1325, Chicago, IL 60611, USA

Abstract

We report two sets of experiments showing that the large individual variability in language learning success in adults can be attributed to neurophysiological, neuroanatomical, cognitive, and perceptual factors. In the first set of experiments, native English-speaking adults learned to incorporate lexically meaningful pitch patterns in words. We found those who were successful to have higher activation in bilateral auditory cortex, larger volume in Heschl's Gyrus, and more accurate pitch pattern perception. All of these measures were performed before training began. In the second set of experiments, native English-speaking adults learned a phonological grammatical system governing the formation of words of an artificial language. Again, neurophysiological, neuroanatomical, and cognitive factors predicted to an extent how well these adults learned. Taken together, these experiments suggest that neural and behavioral factors can be used to predict spoken language learning. These predictors can inform the redesign of existing training paradigms to maximize learning for learners with different learning profiles.

Learning outcomes: Readers will be able to: (a) understand the linguistic concepts of lexical tone and phonological grammar, (b) identify the brain regions associated with learning lexical tone and phonological grammar, and (c) identify the cognitive predictors for successful learning of a tone language and phonological rules.

Keywords

language learning; individual differences; lexical tone; phonology; Heschl's gyrus; Broca's area; basal ganglia; hippocampus

1. Introduction

A particularly challenging aspect of clinical and learning sciences is the large individual differences observed in treatment and training responses. While gold standards of treatment or learning have been reported for different communication disorders or types of learning, these reports focused on group results without detailing the fact that only some patients or learners were responsive. For example, in spoken language learning in adulthood--a type of learning that our research focuses on and shows large variability of learning success-- high

© 2011 Elsevier Inc. All rights reserved.

*Corresponding author: Tel.: +1 847 491 2416; fax: +1 847 491 2429. pwong@northwestern.edu.

Publisher's Disclaimer: This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final citable form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

variability training has been reported to result in the best learning outcome (Bradlow, Akahane-Yamada, Pisoni, & Tohkura, 1999; Lively, Logan, & Pisoni 1993). However, the fact that not all participants learn successfully in these studies means that learners might benefit from redesigned training or treatment that accommodates learners of potentially different learning profiles. This requires first identifying factors that can best predict individual differences in learning/treatment. Here we report two sets of experiments conducted in our laboratory that examined predictors of learning success in two types of spoken language learning. In the first set of experiments, native English-speaking adults learned to incorporate a foreign phonetic contrast in lexically meaningful contexts and behavioral and neural measures were obtained before training in order to understand what factors distinguish successful from less successful learners. In the second set of experiments, we focused on simple and complex phonological grammar learning and identified cognitive and neural factors that were predictive of learning success.

2. Foreign phonetic learning

Extensive research in speech learning has found the learning of many foreign phonemes to be difficult for adults. For example, native Japanese-speaking adults have difficulty learning the English /r/ and /l/ (Bradlow, 2008; Callan, Jones, Callan, & Akahane-Yamada, 2004; MacKain, Best, & Strange, 1981). Studies in speech learning often focus on how to train adults by altering the training program without a careful consideration of why some adults are more successful than others. Our research specifically focuses on finding factors that could explain, to an extent, variance in learning success. In our research on foreign phonetic learning, we focused on the learning of lexical tones, which are pitch patterns that are used to mark word meaning. For example, in Mandarin Chinese, a tone language, the syllable /ma/ can have four different lexical meanings depending on the pitch of the syllable. A large number of world's languages use pitch to contrast word meaning (Yip, 2002), although English is not one of these languages. Lexical tone learning is especially useful for understanding neural differences in speech learning because hypotheses could be developed based on the large body of scientific work on pitch processing. For example, it has been found that the anterolateral portion of Heschl's Gyrus contains a "pitch center" in primates (Bendor & Wang, 2005) and the rostral auditory brainstem faithfully tracks pitch pattern (Greenberg, Marsh, Brown, & Smith, 1987; Krishnan, Xu, Gandour, & Cariani, 2005).

In the first of a series of lexical tone training studies, native English-speaking adults learned to incorporate pitch in lexically meaningful contexts (Wong & Perrachione, 2007). For example, they learned that the syllable [pɛʃ] spoken with a high-level and rising pitch pattern means 'glass' and 'pencil,' respectively. As predicted, we found a range of learning success in these adults. We classified them into two groups based on whether they achieved a 95% accuracy learning criterion. We found that the successful learners showed better performance in a pitch pattern perception task in which they identified the pitch patterns embedded in vowels spoken by multiple talkers.

Our learners also participated in a functional MRI experiment in which they discriminated the pitch patterns of words they learned before and after training (Wong, Perrachione, & Parrish, 2007). When all learners were examined regardless of learning success, increased activation was observed in the left hemisphere including the auditory cortex and prefrontal cortex including Broca's area, similar to what we observed when native tone language speakers perceived lexical tones (Wong, Parson, Martinez, & Diehl, 2004). Most interestingly, successful and less successful learners showed differences both before and after training. After training, successful learners showed a more streamlined brain network that included stronger activation in the left posterior auditory cortex, whereas less successful learners activated a more diffused network including the prefrontal cortex. Most

importantly, differences were also observed before training such that successful learners activated bilateral auditory cortex more strongly. Not only did we find neurophysiological (cerebral hemodynamic) differences, but also neuroanatomical differences. As discussed earlier, the Heschl's Gyrus in primates contains a pitch center (Bendor & Wang, 2005). We manually measured the volume of the Heschl's Gyrus of our learners and found that successful learners had larger volume in both grey and white matter only on the left (Wong et al., 2008). When we considered our three predictors, including pitch pattern perception, bilateral auditory cortex activation, and volume of left Heschl's Gyrus, all measured before training, we found about 61% of the variance in learning explained.

We also considered other factors that could be predictive of learning. For example, we found that more successful learners had musical training (Wong, 2007), perhaps partially due to the fact that musicians showed more faithful pitch tracking as early as the auditory brainstem (Wong, Skoe, Russo, Dees, & Kraus, 2007). We also found that successful learners attended to pitch directional cues more so than less successful learners (Chandrasekaran, Sampath, & Wong, 2010). In our ongoing research, we are examining whether neuroanatomical connectivity, resting-state activation, as well as large-scale functional brain connectivity (Sheppard, Wang, & Wong, 2009) could also be predictive.

3. Phonological grammar learning

Successful spoken language communication not only involves using phonemes in isolation, but also involves learning the rules governing their combination to form words (phonological grammar). For example, in English, the realization of the plural suffix, -s, is governed by a phonological grammar such that it is realized as [s] after voiceless consonants (e.g., *cats*) and [z] after voiced segments (e.g., *dogs*) to avoid combining voiced and voiceless consonants, and as [z] to avoid consecutive alveolar fricatives (e.g., *dishes*). These rules and constraints are specific to each language and there is variability across types of patterns and across individuals in terms of when they are learned in first and second language acquisition (Berko, 1958; Brown, 1973). As with sound learning, we have sought to partially explain this individual variation in learning success by appealing to cognitive, neurological and genetic factors.

Our phonological grammar training studies involve teaching participants an artificial language based on a natural language (Shimakonde, a Bantu language spoken in Mozambique) (Liphola, 2001). The language consisted of two types of words: simple words requiring only affixation to form new words (e.g., *cat*→*cats*) and complex words which also require an additional set of phonological rules to form new words (e.g., *dish*→*dishes*). The phonological rules we used (vowel harmony and vowel reduction) target the vowels of the words and are not present in English, but are relatively common in other languages all around the world (Van der Hulst & van de Weijer, 1995). Therefore, participants learned the artificial language as naïve second language learners. Training involved exposure to word-picture pairings, which exposed participants to both words of the language and the phonological grammar. Assessment of grammatical learning success involves testing participants on their ability to extrapolate the grammatical patterns to new, untrained words in a *wug* test (Berko, 1958).

In one study, we correlated learning success with standardized measures of domain-general memory capacity (Ettlinger, Bradlow, & Wong, 2009). We found that success in the acquisition of the simple grammatical pattern correlated with procedural memory (memory for sequences), while success on the acquisition of the complex pattern correlated with declarative memory (memory for associations), controlling for general intelligence or working memory in both cases.

The neural substrates supporting these memory subsystems are relatively well understood, so these behavioral findings motivated conducting a neuroimaging study to explore the mechanisms underlying these correlations. The fMRI results corroborate the behavioral findings: When participants are acquiring simple patterns, the basal ganglia and Broca's area, which are associated with procedural memory (Knowlton, Mangels, & Squire, 1996), are active, while the hippocampus, which is associated with declarative memory (Eichenbaum & Cohen, 2001), is more active during the acquisition of complex patterns (Ettlinger, et al., 2009). Subsequent analyses show that volumetric measures of relevant cortical areas show the same correlations, and that people who can learn the complex pattern show greater efferent connectivity from the hippocampus to Broca's area (Ettlinger, Novis, Wang, & Wong, 2010).

Because the frontostriatal pathway contains a high concentration of dopaminergic neurons, our ongoing research considers whether polymorphism of genes that are tied to the dopamine system could explain some of the variance in learning.

Combined, these results provide insight into the cognitive mechanisms underlying the acquisition of phonology, suggesting that even the most complex elements of grammar are explainable via domain-general capabilities. Furthermore, by looking at the acquisition of a language very different from English, we can go beyond understanding grammar as procedural rules processed in Broca's area as has been previously argued (Marslen-Wilson & Tyler, 1997; Paradis, 1994; Pinker, 1999; Pinker & Ullman, 2002; Tyler, Marslen-Wilson, & Stamatakis, 2005; Ullman, 2004), to a more complete understanding of phonological grammar as involving the hippocampus as well.

4. Conclusion

Although spoken language learning in adulthood shows large individual variability in success, we found in both speech sound and phonological grammar learning that success can be predicted by neural, perceptual, and cognitive factors to an extent. With these predictors, we are designing experiments to examine altering training paradigms that might enhance the learning of different learners. For example, for lexical tone learning, we have found that certain types of high-variability training could be detrimental to the learning of learners who showed poor pitch pattern perception (Lee, Perrachione, Dees, & Wong, 2007). For phonological grammar learning, we are examining how presentation order for stimuli of different complexity could result in better learning for learners with poor procedural and/or declarative memory. Because of our focus in individual differences and differences in learning success, we hope our results could also be applied to treatment of communication disorders where large individual differences in recovery are often observed.

Acknowledgments

This work is supported by Northwestern University and National Institutes of Health grants R03HD051827, R21DC007468, HD051827, DC007468 and National Science Foundation grant BCS-9986246 to P.W. We thank Jay Mittal, Carson Lam, Ann Bradlow, Diane Arcuri, Gnyan Patel, Arth Srivastava, Purav Jesrani, Andrew Mazotas, Catherine Warrier, Nondas Leloudas, J. Song, B. Williams, J. Alexander, T. Nicol, T. Perrachione, Jack Gandour, Ani Patel, Kai Alter, and Lionel Newman for their assistance and contribution to this research. Visit our website for more information about our research: <http://cns.northwestern.edu>.

References

- Bendor D, Wang XQ. The neuronal representation of pitch in primate auditory cortex. *Nature*. 2005; 436(7054):1161–1165.10.1038/Nature03867 [PubMed: 16121182]
- Berko J. The child's learning of English morphology. *Word*. 1958; 14:150–176.

- Bradlow, AR. Training non-native language sound patterns: Lessons from training Japanese adults on the English/r/-/l/contrast. In: Hanson, JG.; Zampini, ML., editors. *Phonology and Second Language Acquisition*. Amsterdam, PA: John Benjamins Publishing Company; 2008. p. 287-308.
- Bradlow AR, Akahane-Yamada R, Pisoni DB, Tohkura Y. Training Japanese listeners to identify English/r/and/l/: Long-term retention of learning in perception and production. *Perception & Psychophysics*. 1999; 61(5):997-985.
- Brown, R. *A first language: The early stages*. Cambridge, MA: Harvard University Press; 1973.
- Callan DE, Jones JA, Callan AM, Akahane-Yamada R. Phonetic perceptual identification by native- and second-language speakers differentially activates brain regions involved with acoustic phonetic processing and those involved with articulatory-auditory/orosensory internal models. *NeuroImage*. 2004; 22:1182-1194. [PubMed: 15219590]
- Chandrasekaran B, Sampath P, Wong PCM. Individual variability in cue-weighting and lexical tone learning. *Journal of the Acoustical Society of America*. 2010; 128:456-465. [PubMed: 20649239]
- Eichenbaum, H.; Cohen, N. *From conditioning to conscious recollection: Memory systems of the brain*. NY: Oxford University Press; 2001.
- Ettlinger, M.; Bradlow, AR.; Wong, PCM. Neurophysiological evidence of the interaction of memory systems and language learning. Paper presented at the Organization for Human Brain Mapping Conference; San Francisco, CA. 2009 June.
- Ettlinger, M.; Novis, S.; Wang, L.; Wong, PCM. Neuroanatomical correlates of successful language learning. Paper presented at the Organization for Human Brain Mapping Conference; Barcelona, Spain. 2010 June.
- Greenberg S, Marsh JT, Brown WS, Smith JC. Neural temporal coding of low pitch. I. Human frequency-following responses to complex tones. *Hearing Research*. 1987; 25:91-114. [PubMed: 3558136]
- Knowlton BJ, Mangels JA, Squire LR. A neostriatal habit learning system in humans. *Science*. 1996; 273(5280):1399-1402. [PubMed: 8703077]
- Krishnan A, Xu Y, Gandour J, Cariani P. Encoding of pitch in the human brainstem is sensitive to language experience. *Cognitive Brain Research*. 2005; 25:161-168. [PubMed: 15935624]
- Lee, J.; Perrachione, TK.; Dees, T.; Wong, PCM. Differential effects of stimulus variability and learners' pre-existing pitch perception ability in lexical tone learning by native English speakers. Paper presented at the International Congress of Phonetic Sciences; Saarbrücken. 2007 August.
- Liphola, MM. Unpublished doctoral dissertation. Ohio State University; 2001. Aspects of the phonology and morphology of Shimagonde.
- Lively SE, Logan JS, Pisoni DB. Training Japanese listeners to identify English/r/and/l/. II. The role of phonetic environment and talker variability in learning new perceptual categories. *Journal of the Acoustical Society of America*. 1993; 94:1242-1255. [PubMed: 8408964]
- MacKain K, Best C, Strange W. Categorical perception of English/r/and/l/by Japanese bilinguals. *Applied Psycholinguistics*. 1981; 2:369-390.
- Marslen-Wilson WD, Tyler LK. Dissociating types of mental computation. *Nature*. 1997; 387(6633): 592-594.10.1038/42456 [PubMed: 9177345]
- Paradis, M. Neurolinguistic aspects of implicit and explicit memory: Implications for bilingualism. In: Ellis, N., editor. *Implicit and explicit learning of Second Languages*. London: Academic Press; 1994. p. 393-419.
- Pinker, S. *Word and rule: The ingredients of language*. New York: Basic Books; 1999.
- Pinker S, Ullman MT. The past and future of the past tense. *Trends in Cognitive Sciences*. 2002; 6(11):456-463. S1364661302019903 [pii]. [PubMed: 12457895]
- Sheppard, JP.; Wang, JP.; Wong, PCM. Aging effects on cortical network connectivity during speech perception in noise: A graph theoretical analysis. Paper presented at the Organization for Human Brain Mapping Conference; San Francisco, CA. 2009 June.
- Tyler LK, Marslen-Wilson WD, Stamatakis EA. Differentiating lexical form, meaning, and structure in the neural language system. *Proceedings of the National Academy of Sciences of the United States of America*. 2005; 102(23):8375-8380.10.1073/Pnas.0408213102 [PubMed: 15923263]

- Ullman MT. Contributions of memory circuits to language: The declarative/procedural model. *Cognition*. 2004; 92(1–2):231–270. S0010027703002324 [pii]. 10.1016/j.cognition.2003.10.008 [PubMed: 15037131]
- Van der Hulst, H.; van de Weijer, J. Vowel harmony. In: Goldsmith, J., editor. *The handbook of phonological theory*. Oxford: Basil Blackwell; 1995. p. 495–534.
- Wong, PCM. Enhanced lexical tone learning in musicians: Behavioral and neural evidence. Paper presented at the Language and Music as Cognitive Systems; Cambridge, England. 2007.
- Wong PCM, Parson LM, Martinez M, Diehl RL. The role of the insular cortex in Pitch Pattern Perception: The effect of linguistic contexts. *Journal of Neuroscience*. 2004; 24:9153–9160. [PubMed: 15483134]
- Wong PCM, Perrachione TK. Learning pitch patterns in lexical identification by native English-speaking adults. *Applied Psycholinguistics*. 2007; 28:565–585.10.1017/S0142716407070312
- Wong PCM, Perrachione TK, Parrish TB. Neural characteristics of successful and less successful speech and word learning in adults. *Human Brain Mapping*. 2007; 28(10):995–1006. [PubMed: 17133399]
- Wong PCM, Skoe E, Russo NM, Dees T, Kraus N. Musical experience shapes human brainstem encoding of linguistic pitch patterns. *Nature Neuroscience*. 2007; 10(4):420–422.
- Wong PCM, Warrier CM, Penhune VB, Roy AK, Sadehh A, Parrish TB, et al. Volume of left Heschl's Gyrus and linguistic pitch learning. *Cerebral Cortex*. 2008; 18(4):828–836. bhm115 [pii]. 10.1093/cercor/bhm115 [PubMed: 17652466]
- Yip, M. *Tone*. Cambridge: Cambridge University Press; 2002.

Appendix A: Continuing education

1. In primates, where is the “pitch center” located?
 - a. Broca's area
 - b. Wernicke's area
 - c. Heschl's gyrus
 - d. Prefrontal cortex
2. Which one of the following statements about lexical tone learning is true?
 - a. All adult learners can learn very successfully
 - b. Adult learners who do not speak a tone language as their native language cannot learn
 - c. Some adults can learn very successfully, some not so successfully
 - d. Only children can learn.
3. Which one of the following factor(s) have been found to correlate with lexical tone learning?
 - a. Larger right Heschl's Gyrus
 - b. Higher activation in auditory cortex
 - c. Better pitch pattern perception
 - d. b and c
4. “Grammar” can refer to which of the following?
 - a. Syntax
 - b. Phonology

- c. A list of phonemes usable in a language
 - d. a and b
- 5. Which of the following memory subsystems account for a significant amount of variance in acquiring phonology in the cited studies?
 - a. Procedural memory and working memory.
 - b. Procedural memory and declarative memory.
 - c. Declarative memory and working memory.
 - d. None of the above.

Answer key: 1: c; 2: c; 3: d; 4: d; 5: b.