

Age and L2A: An Overview

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The outcome of second language acquisition (L2A) among adults is demonstrably different in many respects from the outcome of first language acquisition (L1A) among children. Departing from this basic observation, researchers attempt to understand the various mechanisms and factors that conspire to produce age-related effects in L2A.

The present paper is an overview of facts and theoretical issues concerning age and L2A. This contribution considers both behavioral data and brain-based processing data. The review includes findings and controversies in the areas of neuro-cognitive development and aging, and cognitive neurofunction in the mature brain.

A comprehensive treatment of the facts and issues is not possible in the space available. It is hoped, nevertheless, that this selective offering provides useful scaffolding for other papers in this issue that examine cognitive and neural aspects of L2 use and acquisition.

BACKGROUND AND TERMINOLOGY

Over the past 20 or so years, a great deal of empirical research on the age question in L2A has focused on the end state of L2A, not on rates of attainment or on stages of L2 development. The developmental literature and comparative rate (adult versus child) literature are certainly not without interest, and overviews of this research can be found in Klein (1995), Marinova-Todd et al. (2000), and Pienemann et al. (2005).

However, it is essential that the end state receive its share of attention, because it is evidence from the end state that determines the upper limits of L2 attainment. Knowing the potential of the learner permits inferences about the nature of putative constraints on acquisition, including their relative strength and ultimate impact on learning (see Long, 1990, pp. 253-259). Accordingly, the end state is the focus of the present paper.

Both as a matter of logic and as a matter of theoretic adequacy, it is important to recognize that, when comparing L1A and L2A, a superficial difference in ends does not necessarily imply an underlying difference in means. Nor does similarity of ends/products necessarily imply similar means/processes. Thus, for example, with respect to the question of Universal Grammar's mediating role in L2A, we understand that nativelikeness at the L2A end state does not imply access to UG; at minimum a poverty-of-the-stimulus demonstration must be made. By the same token, it is clear that non-nativelike linguistic behaviors are not necessarily evidence of lack of access to UG. Researchers must be wary of linking end-state differences in L1A and L2A exclusively to a loss of general learning ability, or exclusively to some erosion of any putative mechanism(s) responsible for successful L1A. Thus linkages between product and process are to be established only with due caution.

In the literature, the terms end state, final state, steady state, ultimate attainment, and asymptote are used more or less interchangeably to refer to the outcome of L2A. Note that "ultimate attainment" has occasionally and erroneously been used as a synonym for nativelike proficiency. However, the term properly refers to the final product of L2A, whether this be nativelike attainment or any other outcome. For divergent views of the construct of "end state" in L2A, see Birdsong (in preparation), Larsen-Freeman (in press)

and White (2003). For discussion of operationalizing the L2A end state, see Birdsong (2004).

Researchers have explored several biographical variables that might be predictive of L2A outcomes. Age of acquisition (AoA) is understood as the age at which learners are immersed in the L2 context, typically as immigrants. This landmark is distinct from age of first exposure (AoE), which can occur in a formal schooling environment, visits to the L2 country, extended contact with relatives who are L2 speakers, etc. Researchers tend to equate the terms late L2A, post-adolescent L2A, and post-pubertal L2A; these are typically operationalized as AoA of > 12 years. Length of residence (LoR) refers to the amount of time spent immersed in the L2 context. Because residence does not guarantee exposure to and use of the L2, researchers quantify the actual amount of contact L2 learners have with the L2 (in spoken and written modalities), and the relative use of the L1 versus the L2 in day-to-day activities. Other experiential variables include amount of formal training in the L2 as a foreign language (e.g., grammar courses, corrective phonetics) as well as amount of exposure to the L2 in so-called content courses, where non-natives are enrolled in high school, vocational, or university classes in the L2 country.

Endogenous variables of interest to L2A researchers include: motivation (with several subtypes relating to outcome, e.g., motivation to pass for a native, motivation to acquire lexico-grammatical accuracy, etc.); psycho-social integration with the L2 culture; aptitude (with several presumed components including imitative ability, working memory capacity, metalinguistic awareness, etc.); and learning styles and strategies. These are understood to be continuous, not all-or-nothing, variables. For overviews of these variables see Dörnyei and Skehan (2003) and Doughty (2003).

AOA AND L2A ULTIMATE ATTAINMENT

It is widely recognized that AoA is predictive of L2A outcomes, in the simple sense that AoA is observed to significantly correlate negatively with attained L2 proficiency at the end state. This conclusion is based on the results of more than two dozen experimental studies; see Birdsong (2005) and DeKeyser and Larsen-Hall (2005) for overviews. The areas of language most commonly investigated are morphosyntax and pronunciation. Typically, morphosyntax errors in production or grammaticality judgments increase with advancing AoA, as does degree of judged non-native accent.

Across many studies that examine AoA and other factors that may be related to L2 success, it has emerged that, of all the experiential variables mentioned above, AoA is reliably the strongest predictor of ultimate attainment. This is not to say that other variables, indeed some that are confounded with AoA, are not predictive. In many cases, variables such as LoR and AoE are controlled statistically or included as factors in the experimental design. Discussion of these variables, and associated methodological concerns, may be found in Birdsong (2005; in preparation).

The age function. From the actual behavioral data, a recurrent finding is that a linear function captures the relationship between AoA and outcome over the span of AoA (that is, when considering aggregate data from both early and late-AoA subjects). In ten surveyed studies, the range of correlations is .45 to .77, with a median of about .64 (all absolute values).¹ The slope of the age function varies (i.e., it is steeper or shallower) as a function of such factors as L1-L2 pairing, amount of L2 use, task, education in the L2, and so on. It

is also not surprising to find, given what is known about learning and cognitive performance over the lifespan (Schaie, 1994; Weinert & Perner, 1996), that there is less inter-subject variation in outcome among early arrivals than among late arrivals.

When data from early- and late-AoA subjects are disaggregated, inconsistent results are obtained, producing a clouded picture of the timing and geometry of the age function. For example, DeKeyser (2000) studied 57 Hungarian L1 English L2 subjects with AoA ranging from 1 to 40 years, all with at least 10 years of US residence. On a grammaticality judgment test using some items from Johnson and Newport (1989) along with some novel items, a significant correlation of AoA with scores was obtained ($r = -.63$, $p < .001$). However, when DeKeyser broke out the data by early and late-arriving subjects, neither set of data yielded a significant correlation with AoA (early arrivals $n = 15$, $r = -.24$, ns; late arrivals $n = 42$, $r = -.04$, ns).

Another illustration of the disparate results of analyses of aggregate versus disaggregated data is seen in the comparison of the results of Johnson and Newport (1989) and Birdsong and Molis (2001). Johnson and Newport looked at accuracy on a 276-item grammaticality judgment by a group of Chinese and Korean natives ($n = 46$) with English as their L2. The Birdsong and Molis study was a strict replication of Johnson and Newport, but in this case the subjects were Spanish natives ($n = 61$). Over all subjects and AoAs, Johnson and Newport found a strong linear relationship between AoA and accuracy ($r = -.77$, $p < .01$). This finding was reproduced by Birdsong and Molis ($r = -.77$, $p < .0001$). However, when the subjects were divided into AoA groups of ≤ 16 years and ≥ 16 years, the analyses produced divergent results. Figure 1 represents these differences.

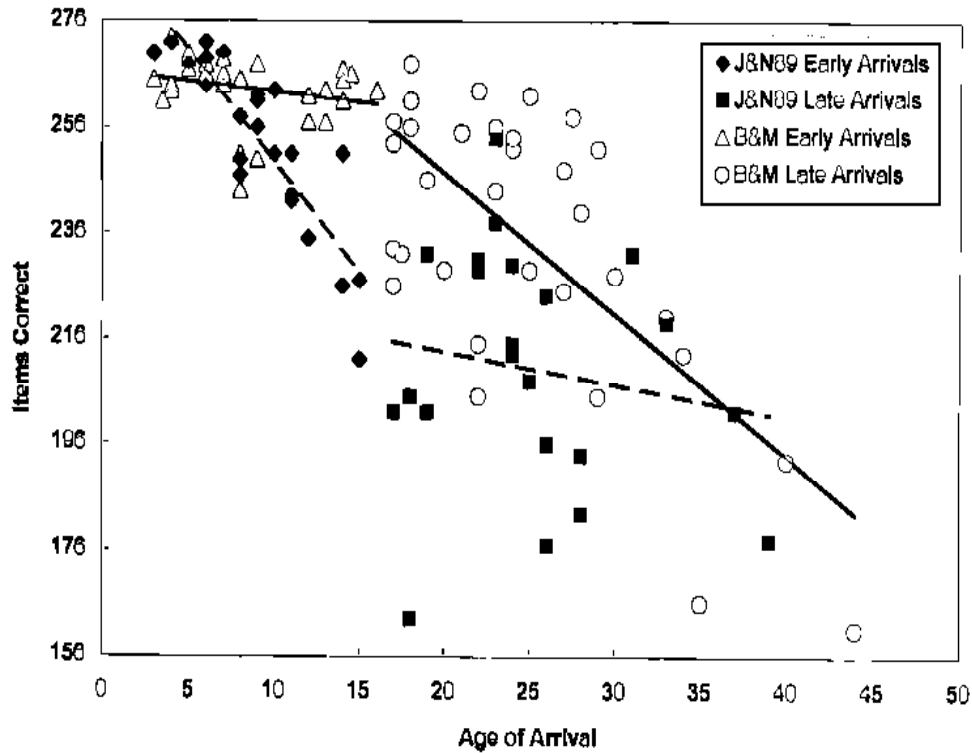


Figure 1. Plot of accuracy over AoA from Birdsong and Molis (2001, p. 240). Solid regression lines are fit to the Birdsong and Molis data; dashed lines are fit to the Johnson and Newport (1989) data. Early and late AoA groups are divided at 16 years.

The pattern of results seen in Johnson and Newport is a decline in scores with increasing AoA for early arrivals ($r = -.87, p < .01$) and an essentially random distribution of scores for the older-arriving group ($r = -.16, ns$). A quite different pattern is obtained by Birdsong and Molis. For early arrivals the correlation of scores with age is not significant ($r = -.24, p = .22$), as this subgroup performed at ceiling. For late arrivals, the correlation is strongly negative ($r = .69, p < .0001$).

In a re-examination of the Johnson and Newport (1989) data, Bialystok and Hakuta (1994) moved the cutoff point separating early and late-arriving groups to 20 years. For late learners, the subsequent correlation reached significance ($r = -.50, p < .05$). Birdsong

and Molis (2001) conducted a similar re-analysis of their data, placing the cut-off at various ages between 15 years and 27.5 years; all correlations reached significance.

As Birdsong (in preparation) notes, the picture becomes even more nuanced when other statistical methods and other linguistic behaviors are brought into play. For the present purposes, it suffices to present three conclusions reached in the meta-analysis by Birdsong (2005) of L2 end-state morphosyntactic and pronunciation behavioral research.

(1) In all analyses of pooled data from early and late arrivals, age effects persist indefinitely across the span of surveyed AoA, i.e., they are not confined to a circumscribed period; (2) In analyses of disaggregated samples (and in studies that look only at late AoA), most studies find significant AoA effects for the late learners, indicating postmaturational declines in attainment; (3) In analyses of early arrival data alone, AoA effects are inconsistent: some are flat, some are random, and some are monotonically declining.

ISSUE #1: Do observed AoA effects suggest a maturationally-based critical period?

We may now take a step back and consider whether observed AoA effects can be interpreted as critical period effects.² If what we are dealing with is in fact a period, the age effects observed in the data must be confined to a finite time span; see Bornstein (1989) for further discussion of characteristics of a critical period. Moreover, if the effects are maturational in nature, then the age function prior to the end of maturation should look different from the age function after the end of maturation.

Taken together, the requirement of finite age effects and a discontinuity in the age function synchronized with the end of maturation permute into three basic patterns. One is a stretched “L” or hockey stick shape, with age-related declines ceasing at a point of

articulation that coincides with the end of maturation. The second is an upside-down mirror image of the stretched “L”, resembling a stretched “7”. The flat portion at the top left of the image is the period where success is guaranteed. A third possibility, laid out by Johnson and Newport (1989) and expanded by Pinker (1994), specifies a causal role of brain maturation in L2A age effects, with the end of age effects synchronized with the completion of brain maturation. This version combines features of the first two possibilities to produce the image of a stretched “Z”. The function begins with a period of ceiling effects, followed by a decline that ceases at the end of maturation, after which the age function flattens and no further age effects are seen.

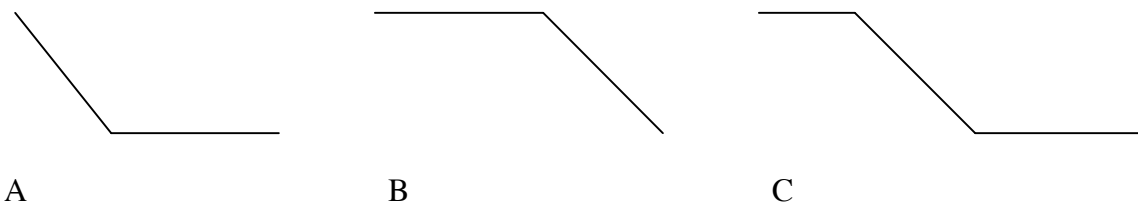


Figure 2. Three patterns of bounded age effects. A: Stretched “L” shape; B: Stretched “7” shape; C: Stretched “Z” shape.

Let us consider the third possibility first. The stretched “Z” shape (Figure 2C) includes two finite periods. At the upper left portion of the image, where performance is at ceiling, we indeed observe a bounded period, which is actually a period during which age effects are absent, as there is no downward slope in the age function. The next segment is a bounded downward slope; the age effect begins pre-pubertally and ends at the completion of maturation. The third segment, which is unbounded, captures the hypothesized bottoming-out or flattening of the age function. Johnson and Newport (1989) purport to have

produced findings consistent with the timing and geometric features just described. However, instead of an orderly array of scores parallel to the X-axis—that is, the hypothesized floor effect—one finds a random dispersion of points. In other words, the crucial flattening feature of the function, whose beginning should coincide with the end of maturation, is in fact not present in the data (Birdsong, 2005).

Moreover, as mentioned earlier, if following Bialystok and Hakuta (1994) one moves the cut-off point to 20 years, the late-arrivals data in Johnson and Newport (1989) start to look a bit more orderly. The result of the ensuing analysis is neither a random distribution nor a floor effect, but a significant negative correlation of AoA and performance for the late-arriving group.

The stretched “L” or hockey-stick representation (Figure 2A) incorporates a sloping segment on the left that would satisfy the requirement of a bounded period during which AoA is negatively correlated with outcomes. It also contains a flattened segment, the beginning of which coincides with the end of maturation. A review of the literature (see Birdsong 2005; DeKeyser & Larson-Hall, 2005) reveals that several analyses of disaggregated data show pre-maturational declines—the left portion of the stretched L. However, for later learners (i.e., those whose performance would be represented by the right segment of the stretched L), there is no evidence of a flat function or floor effect. Instead, for late learner groups there is either a random array of scores (e.g., DeKeyser, 2000; Patkowski, 1990) or a persistent decline in performance with increasing AoA (e.g., Bialystok & Miller, 1999; Birdsong, 1992). Returning to Figure 2A, we note that the *appearance* of a stretched “L” shape (i.e., the two rightward segments the “Z”) of is obtained for the Johnson and Newport (1989) data when linear functions are applied

separately to early and late arrival data. A systematic performance decline over AoA is indeed observed for early arrivals ($r = -.87$). However, as we saw earlier, for late arrivals a flat segment is a misleading representation of the correlation coefficient in this instance ($r = -.16$), as the best-fitting near-horizontal regression line actually goes through a random array of scores, and not through an orderly set of points that are parallel to the X-axis.

The final scenario by which age effects would be considered critical period effects is the mirror image of the one just discussed, a stretched “7” or upside-down hockey stick shape with the “blade” at the top left (Figure 2B). This is an unconventional, though often implicitly invoked, notion of a critical period function (see Birdsong, 2005 for discussion of conventional and unconventional conceptions, based on Bornstein, 1989). The leftmost part of the function is flat, with performance at ceiling. On the right portion of the image, the age gradient, i.e., the decline in ultimate attainment with advancing AoA, is not bounded. What is bounded is the left segment of the image, the period of peak attainment, which is often referred to as a “window of opportunity,” the temporal span during which sensitivity or learning potential is at its highest and full attainment is guaranteed. Certain studies that find near-zero correlations of AoA with results for early arrivals do *not* in fact find bounded periods of highest attainment (e.g., DeKeyser, 2000; Patkowski, 1990). However, such a period has been observed in at least one study, Birdsong and Molis (2001). As seen in Figure 1 above, a roughly flat function at ceiling is generated by the performance of the early-arriving AoA group of Spanish L1 speakers. While this “age non-effect” is confined to temporally-limited span—thus satisfying the geometric period criterion and corresponding to the unconventional “window of opportunity” version of the critical period—the temporal features do not conform to a maturational account of AoA effects. For

their L2 learners' results, Birdsong and Molis (2001, pp. 241-242) conducted a series of post-hoc piecewise regression analyses that included the inflection point (i.e., the terminus of the period) as a free parameter. Under these conditions, the best-fitting function placed the end of the ceiling period, and thus the beginning of the decline, at 27.5 years. In other words, the period of peak performance extends 10 or more years beyond the end of maturation. Thus, while the Birdsong and Molis results reveal stretched "7" shape and its circumscribed period of full attainment, the temporal parameters do not mesh with a maturational-effects account of L2 ultimate attainment.

ISSUE #2: Divergent conceptualizations of "critical period". Singleton (in press) examines several proposals for the timing of the "end of the critical period". In most cases, these proposals make reference to the end of the period of peak sensitivity, that is, they invoke the "window of opportunity" notion of critical period. In the studies Singleton surveys, hypothesized beginnings of declines range from near birth to late adolescence. Some proposals make distinct timing claims for phonetics/phonology versus other areas of linguistic knowledge and performance. Such so-called "multiple critical period" accounts of attainment in various language domains of are advanced by Long (1990) and Seliger (1978) for the L2 context, and are consistent with current neurobiological thinking about critical periods in other contexts (Knudsen, 2004).

The proposals of Lenneberg (1967), Seliger (1978), Scovel (1988), Johnson and Newport (1989), Long (1990), and Pinker (1994) signal changes that occur around puberty. Significantly, in some cases this maturational milestone is thought to be the point at which declines in performance *begin* (i.e., the unconventional notion of critical period),

and in other cases the point at which performance declines *cease* (the conventional notion). Thus a serious conceptual issue confronts proponents of a maturational account of constraints on L2A attainment: does maturation determine the beginning of age effects or the end of age effects?

Empirically, neither account of the timing of maturational effects fares very well. As discussed above, it is now understood (e.g., Birdsong, 2005; Hyltenstam & Abrahamsson, 2003) that the behavioral data are generally inconsistent with either a period of peak sensitivity whose end coincides with the end of maturation, or with a leveling-off of sensitivity whose beginning coincides with the end of maturation. For additional commentary on the timing of age effects, see Moyer (1999).

INCIDENCE OF NATIVELIKE ATTAINMENT IN LATE L2A

Like the facts about the age function, the facts relating to nativelike attainment in L2A do not lend themselves to simple generalization. Moreover, as was the case with the age function, the interpretation of these facts is not without controversy.

Historically, research in L2A has been guided by what has been termed the deficit model. Characterizing the end state of L2A as a “lack of success,” research in this tradition looks to explain the “near-universal failure” of adults to reach attainment comparable to that observed in L1A (Bley-Vroman, 1989). The prevailing view was that nativelikeness, if ever observed, was so rare as to be of no relevance to L2A theory (e.g., Bley-Vroman, 1989; Selinker, 1972). Estimates of a 0 to 5% incidence of nativelikeness were more a matter of guesswork than experimentation, and were apparently pegged to a population that included foreign language learners and others who were not at the L2A end state. More

recently, however, a number of studies have targeted immigrants with sufficient LoR and contact with natives to qualify for end-state status and have scrupulously attempted to ascertain the rate of nativelikeness in the sample. The findings of these studies suggest that nativelikeness in late L2A is not typical, but neither is it exceedingly rare.

More than 20 studies have reported the rate of nativelikeness among late (AoA \geq 12 years) L2A learners. In these studies, the incidence of nativelikeness ranges from 0% to 45.5%. Nativelikeness is observed in tasks eliciting L2 pronunciation as well as in tasks probing morphosyntactic and other grammatical knowledge.

Anecdotal evidence, along with some research, suggests that nativelikeness is attested less often in the domain of pronunciation than in other performance domains. Though the incidence of nativelike pronunciation may be lower than for morphosyntax, it is not impossible, as studies by Birdsong (2003) and Bongaerts and colleagues (see Bongaerts, 1999, for summaries of their studies) have shown. Both Birdsong and Bongaerts suggest that phonetic training is helpful and perhaps necessary in attaining nativelike pronunciation in late L2A. The perceptual abilities underlying unaccented L2 pronunciation have proved to be amenable to training in some studies (e.g., McCandliss et al., 2002; Bradlow et al., 1997) but resistant to training in others (e.g., Takagi, 2002: see Darcy, Peperkamp & Dupoux, submitted, for an overview). Across domains of performance, the likelihood of nativelikeness varies as a function of L1-L2 pairing, amount of L2 input and interaction, and training. For further discussion, see Birdsong (2004, 2005).

ISSUE #3: Domains of nativelikeness. There exists a widespread belief (Long, 1990; Hyltenstam & Abrahamsson, 2000, 2003; Scovel, 1988) that nativelike attainment by late L2 learners, if observed at all, will be confined to one or a few tasks, and that an individual will not display nativelikeness across a variety of linguistic behaviors (or experimental performances). The coinage “Joseph Conrad effect” captures this notion. However, recent work suggests that the attainment of broad nativelikeness among late L2 learners is in fact possible. In a study of end-state L2 English acquisition, Marinova-Todd (2003) recruited 30 late learners (AoA > 16, mean 11 years) with at least 5 years’ residence (mean = 11 years) in an English-speaking country. These subjects had been informally screened for high English proficiency and, like the 30 native controls, were college educated. Nine tasks targeted an array of linguistic performance. Two tasks related to pronunciation, one for spontaneous speech and one for read-alouds; three tasks tested morphosyntactic accuracy in both off-line and on-line performance; two tasks probed lexical knowledge in oral descriptions; and two tasks involved language use in narrative and discourse. Of the 30 late learners, 3 performed to nativelike criteria across all 9 tasks. Six others were indistinguishable from natives on 7 tasks. The results of this study are of particular interest because the performances tested include not only the core areas of grammar and pronunciation but also lexical diversity and narrative and discourse competence. Moreover, some of the tasks used by Marinova-Todd do not involve reflection and metalinguistic analysis, thus muting the argument that non-nativelikeness will inevitably be ferreted out in spontaneous language use (Hyltenstam & Abrahamsson, 2000, 2003). See Birdsong (2003) and Ioup et al. (1994) for additional evidence of broad nativelikeness in late L2A.

ISSUE #4: Determining the upper limits of late L2A. Another indication of learner potential is the preliminary finding that there is no feature of grammar (in the Chomskyan sense) that cannot be mastered to nativelike levels by later L2 learners. This conclusion has been derived from surveys of multi-task and single-task studies, which indicate that nativelike performance is not out of reach of all participants (Birdsong, in press). The varied tasks and structures involved were challenging and indeed some were considered to be out of reach for late learners.

While the heuristic for grammar learning in L2 is universal learnability, for on-line language processing, the relevant heuristic is selective processability. That is, some but not all L2 processing is carried out by late learners in the same way as natives. Differences between highly-proficient late L2 learners and monolingual natives have been noted in the areas of lexical retrieval, structural ambiguity resolution, and detection of acoustic distinctions in the areas of syllable stress, consonant voicing, and vowel length (e.g. Clahsen & Felser, in press; Dussias, 2004; Dupoux & Peperkamp, 2002; Papadopoulou & Clahsen, 2004). The differences appear to be both quantitative (speed, accuracy) and qualitative (e.g., parsing in a structurally shallow manner; mishearing segments). A review of sentence processing differences revealed by ERP and eye-tracking studies is found in Frenck-Mestre (2005).

ISSUE #5: Use of evidence of (non-)nativelikeness. There is ongoing discussion about the relevance to L2A theory of behavioral evidence showing end-state nativelikeness and non-nativelikeness. Should researchers dig around for any soupçon of non-nativelikeness

and declare this to be proof that learning mechanisms are rendered defective by aging? The practice of “gotcha science” is questionable. Moreover, the use of a non-native lexical item—say, in a moment of passion—should not be taken as evidence of defective learning. Are small quantitative differences (e.g., shorter-than-native-norm VOT values), especially averaged over subjects, sufficient demonstrations of learning failure? Considering that the L1 VOT values of bilinguals tend to move outside of the native range toward L2 VOT values (and L2 values move toward L1 values), it is more plausible to argue that minor quantitative departures from monolingual values are artifacts of the nature of bilingualism, where each language affects the other and neither is identical to that of a monolingual. To put a finer point on this observation, L2 effects in the L1 have been demonstrated for VOT (Flege & Hillenbrand, 1984; Mack, Bott, & Boronat, 1995), collocations (Laufer, 2003), middle voice constructions (Balcom, 2003), syntactic processing (Cook et al., 2003), and lexical decision (Van Hell & Dijkstra, 2002).

Inherent in bilingualism are effects of the L1 on the L2 and vice versa. It would be absurd to suggest that defective learning of the L1 underlies changes in the L1 among bilinguals, which produce non-monolingual-nativeness in the L1. By the same token, it should not be argued that all non-monolingual-nativeness in the L2 of a bilingual is the result of defective learning mechanisms.

ISSUE #6: L2 Dominance. To conclude our consideration of nativeness in late L2A, we note that investigations of the upper limits of attainment in late L2A could profit by targeting an under-represented group, namely late L2 learners who are L2 dominant. For example, Flege, MacKay, and Piske (2002) looked at the English pronunciation of three

groups of Italian L1/English L2 bilinguals: L1-dominants, balanced bilinguals, and L2 dominants. The researchers found both L1-dominants and balanced bilinguals had detectable accents, while the pronunciation of L2-dominant bilinguals was indistinguishable from that of native controls. Flege et al. speculate that, in the area of pronunciation at least, L2-dominants are less likely to be subject to interference effects from the L2. Whether or not this speculation proves tenable, researchers should recognize the possibility that data from high-L2-proficients may not give the full picture of the capacities of late L2 learners.

Dominance is a continuous construct; that is, the degree of L2 dominance, as operationalized by performance on quantitative psycholinguistic measures such as numbers of words extracted from L1 versus L2 speech amid background noise, varies from one individual to another. One may hypothesize that the degree of L2 dominance is predictive of degree of monolingual-like performance on measures of L2 processing and possibly L2 knowledge. (It may in fact turn out that degree of L2 dominance is a better predictor in this respect than AoA.)

ISSUE #7: L1 effects in L2 acquisition and processing. The preceding discussion hinted at a constraining role of the L1 in L2 ultimate attainment and L2 processing. Two general types of L1 effects can be distinguished. Specific L1 effects are noted in the various slopes of the age gradient for subjects of different L1 backgrounds learning a given L2. We also observe different “accents” (not only in pronunciation but also in error patterns in morphosyntax and in biases in auditory and syntactic processing) that native speakers of different L1s have in a given L2. General L2 effects are observed in comparisons of high-

L2-use subjects with low-L2-use subjects: higher L2 users have greater incidences of nativelikeness and generally higher L2 proficiency levels than low L2 users. For discussion of L2 use (and L2 input) variables, see Flege, Frieda, & Nozawa, 1997; Flege & Liu, 2001; Flege, Yeni-Komshian & Liu, 1999).

What is the independent contribution of L1 knowledge to the slope and timing of the age function? Since degree of L1 entrenchment (on L1 entrenchment, see Kuhl, 2000; MacWhinney, 2005, *inter alia*) correlates with age, the loadings of L1 use and proficiency factors could be determined through statistical methods. It would also be potentially revealing to determine the temporal and geometric features of the age function for subjects who have zero residual knowledge and use of the L1 (e.g., the Korean adoptees who were moved to France and had no subsequent contact with Korean; see Pallier et al., 2003), and compare these results with those for subjects whose contact with, use, and knowledge of the L1 is varied systematically.

AGE AND NATIVELIKENESS IN BRAIN-BASED MEASURES

As a complement to linguistic and metalinguistic data, brain-based evidence illuminates important dimensions of the question of age and L2A. A number of recent reviews give more breadth and depth to discussion of relevant research than space permits here (e.g., Abutalebi, Cappa, & Perani, 2005; Stowe & Sabourin, *in press*). See also Green (2005) and Paradis (2004, 2005) for discussion of the limitations of, in particular, localization research using imaging techniques.

ISSUE #8: L2 processing = L1 processing? The basic research issue addressed in this area of cognitive neuroscience is whether processing in the L2 is accomplished in the same way as processing in the L1. The degree of observed similarity hinges on three principal factors: the age at which L2 acquisition is begun, the level of L2 proficiency, and the type of task demanded of the subjects. As one would expect with any complex cognitive activity, some of the most revealing results relate to interactions between these factors.

When comparing L1 and L2 processing, we may be referring to the psychology of cognition (e.g., automatic versus controlled processes; implicit versus explicit knowledge), the nature of mental representations (e.g., symbolic versus sub-symbolic representations; encapsulated versus distributed representations) the general area of the brain that is activated (e.g., involvement of cortical versus sub-cortical regions; left hemisphere versus right hemisphere), or, within a given region of the brain, the particular neuronal circuits engaged in language processing.

Interwoven throughout these various levels of analysis is the theme of plasticity and aging. In its most basic sense, plasticity refers to the capacity of a cognitive system or neuronal structure to do the job at Time Y that it was capable of doing at Time X. Intervening between Time X and Time Y may be various biological processes (e.g., myelination and demyelination, neural pruning, dedifferentiation) or experiences (e.g., L1 learning, use, and entrenchment, via Hebbian strengthening of connections; ‘perceptual magnet’ effects). Plasticity has also been used in the sense of compensation and equipotentiality, i.e., the recruitment of a system or structure to perform the job normally performed by another system or structure.

AoA and proficiency: imaging studies. Early research (e.g., Kim et al., 1997) showed cortical activation differences between late and early bilinguals in L2 production tasks. It was tempting to conclude from these findings that later AoA results in non-nativelike brain activity patterns. However, subsequent investigations have controlled for or manipulated the factor of L2 proficiency.

In studies of production, it is L2 proficiency level, not AoA, that emerges as the strongest predictor of degree of similarity between late learners and monolingual natives. This conclusion must be qualified, however, as the degree of similarity varies from study to study. Moreover, what is meant by “production” is also quite variable, with tasks ranging from word repetition (Klein et al., 1994), to (typically cued) word generation (Chee et al., 1999; Klein et al., 1995), to sentence generation (Kim et al., 1997), to cognate and non-cognate naming (De Bleser et al., 2003). Finally, from study to study there are exposure differences and degree of proficiency differences that make comparisons and generalizations difficult.

In comprehension studies (of which there are relatively few), similar issues of incommensurability must be taken into account. Still, a coherent pattern of sorts emerges. For story listening tasks, two studies (Perani et al., 1996 [PET]; Dehaene et al., 1997 [fMRI]) found differential activation between natives and low-proficient late learners. But when Perani et al. (1998) compared high-proficiency late and early bilinguals on story listening (PET), overlapping patterns of brain activity were found.

Two fMRI studies involving comprehension, then judgment, are of note. Chee et al. (2001)’s fMRI study of high and low-proficiency bilinguals found that highly proficient subjects (AoA \geq 12 years) had relatively reduced brain activity in left prefrontal and

parietal areas. The fMRI study of Wartenburger et al. (2003) involved semantic and grammar judgments by 3 groups of Italian-German bilinguals divided by AoA and proficiency (early bilinguals/high proficiency; late bilinguals/high proficiency; late bilinguals/low proficiency). Activation for grammar judgments was related to AoA: the two high proficient groups with different AoA showed different activations, the activations being more extensive across Broca's and other areas for the later learners. However, the authors point out that some differences may have been related to proficiency, as the nominally equal proficiency groups actually differed in grammaticality judgment accuracy. Similarities in activation for semantic judgments were seen among higher-proficient bilinguals. However, in the semantic judgments a somewhat greater extent of activation in bilateral BA 47 and insula was observed for late versus early high-proficient subjects.

Studies of word-level meaning and reference (Chee et al., 2000; Xue et al., 2004; Ding et al., 2003) have shown similarities in areas of activation in L1 and L2. In the case of Xue et al. (2004), where subjects were asked to judge whether pairs of words were related, relatively late learners Chinese learners of English (age of exposure between 8 and 10) with rather low proficiency (subjects had had 2 years of English study and no other exposure or practice) showed activations in both L1 and L2 in the fusiform gyrus, Broca's area, and left parietal lobe.

Within the finding of general congruence of brain areas activated in L1 and by proficient late bilinguals, the degree of activation may be different. Specifically, more neuronal activity in a given area is seen in L2 versus L1 processing, as indicated by either more voxels in given area being activated or by more signal change for the same voxels. This pattern has been observed for early bilinguals as well as late bilinguals. These indices

correspond to increased neural activity in a specified area, and the extra activity is interpreted as the L2 being processed with more effort than the L1 (Stowe & Sabourin, in press).

For discussion of the relationship of extent of activation to proficiency in the two languages, see Wartenburger et al. (2003, pp. 167-168). For discussion of the extent of activation pattern changes with aging, see Park and Gutchess (2005, pp. 237-238).

AoA and proficiency: ERP studies. Broadly speaking, the ERP literature relating to the When of language processing is consistent with the fMRI and PET literature that speaks to the Where question. That is, the timing components of high-proficient L2 use are by and large similar to those of L1 use, even when acquisition of L2 was begun at age 12 or later (e.g., Hahne, 2001; Hahne & Friederici, 2001; Proverbio et al., 2002; Ojima et al., 2005; Stowe & Sabourin, in press;) From the ERP studies, as with imaging studies, it appears that there is general support for the “convergence hypothesis” articulated by Green (2005), which states that as L2 proficiency increases, the processing profile in the L2 becomes more similar to that of native L1 use.

Recent research suggests that the similarities appear earlier in the course of adult L2 learning than had been previously thought. For example, McLaughlin et al. (2004) found P600 effects for syntactic violations after just four months of L2 learning, and Osterhout et al. (2004) demonstrated natively-like word versus pseudo-word N400 effects after only 14 hours of instruction. The corresponding behavioral results for the subjects were not natively-like, suggesting that the amount of L2 learning taking place may be understated in behavioral data (see also Indefrey et al., 2005; Mueller et al., 2005).

On the other hand, the study by Sabourin (2003) suggests that behavioral measures may overstate similarities, while ERP may pick up on differences, at least among mid-proficiency L2 learners of different L1 backgrounds. Subjects were late learners (> 12 years AoE) of Dutch from German, Romance, and English native-language backgrounds. On grammaticality judgments of verb feature agreement, all three learner groups performed at about 90% accuracy (native controls' accuracy = 97.4%). However, the groups differed in terms of ERP signals recorded as the judgments were being made. The German group showed roughly nativelike N400 and P600 responses, while the Romance and English groups displayed no early negativity and their P600 was delayed and smaller relative to native control data.

THE AGING BRAIN

The next descriptive component in our consideration of age and L2A consists of facts about the aging brain, with which explanatory accounts of age-related differences in ultimate attainment must be compatible. Neurocognitive features of aging are amenable to investigation at various organizational and analytic levels. Those relevant to language learning and use include the functional/processing level (lexical encoding and retrieval; processing speed and depth; concatenation and coordination of grammatical units in real time, etc.); the functional/learning level (Hebbian learning; declarative memory and procedural memory, etc.); the brain structure level (hippocampus, striatum, etc.); and the cellular level (neurotransmission; regional volumetric decline; neurogenesis; etc.). The basic consideration is the degree and locus of age effects at these various levels of analysis.

ISSUE #9: L2A and cognitive aging. From the work of Bäckman and colleagues (e.g., Bäckman et al., 2001) Park (e.g., Park, 2000), Salthouse (e.g., Salthouse, 1996), and others, we have come to recognize several general patterns in cognitive aging. In tasks that tap working memory and episodic memory, there is an observed performance decline over age, starting in young adulthood. Declines in associative memory and incremental learning also appear to begin in young adulthood. On tasks involving priming, recent memory, procedural memory, and semantic memory, age-related effects, when observed, are comparatively mild (Craik, 2000, pp. 78ff). Age effects are also comparatively mild for implicit memory tasks versus explicit memory tasks relating to lexical recall (Park, 2000, pp. 7-8).

Similar discrepant effects of aging are seen when fluid intelligence is compared to crystallized intelligence. On tasks involving fluid intelligence (e.g., Digit Symbol), which involve speeded solutions of novel problems, performance declines in a steady manner over the adult life span. However, on tasks that draw on crystallized intelligence and do not have a speeded component, declines begin only in late adulthood, and performance may even increase from early adulthood to middle adulthood.

For native language users, vocabulary knowledge is an example of crystallized intelligence, and this intelligence is put to use in on-line language comprehension. For low-proficient L2 subjects, much of the lexicon is not established as crystallized intelligence. We can therefore reasonably posit that for the low-proficient L2 user, the proportion of fluid intelligence versus crystallized intelligence involved in language use is greater than the proportion involved in L1 use. As fluid intelligence is more affected by

age than crystallized intelligence, the impact of age will correspondingly be more pronounced in L2 use than in L1 use.

Researchers have identified three principal mechanisms of cognitive aging (Park 2000): decreases in processing speed, deficits in working memory, and decreases in suppression, i.e., the ability to focus attention on relevant material which some link to working memory (see also Rogers, 2000). Each of these abilities is involved in some stages of L2 acquisition, and routinely in language use (L1 and L2). Among bilinguals, working memory may be involved in controlling the activation of the two languages (see Kroll & Tokowicz, 2005; Michael & Gollan, 2005), which may be tied to a general ability to suppress irrelevant information (see Anderson, 2003; Michael & Gollan, 2005). Research has shown that for the typical L2 user (i.e., who has non-nativelike proficiency, and is not L2-dominant) these abilities are not as robust in L2 as in L1. With increasing age, both L1 and L2 use are affected via declines in these underlying components of language processing. Age effects on these components in L2 use are likely to be more pronounced than in the L1 case, due to a relatively low degree of automaticity in L2 processing (Segalowitz & Hulstijn, 2005) and, as mentioned earlier, less crystallized linguistic knowledge in L2 than in L1.

On tasks where speed and efficiency demands are made, and when relatively new information is involved, two features of the age gradient stand out. First, the onset of performance decline begins in early adulthood (around age 20). Second, the decline across the adult lifespan is generally linear, and in all cases are continuous (Bäckman & Farde, 2005, p. 68). Note that within the general trends in cognitive performance there is a range

of variation among individuals; these should play out in L2A as inter-individual differences in ultimate attainment.

ISSUE #10: Age, brain volume, and L2A. In this section we speculatively explore the possibility of a connection between brain volume decreases in aging and declines in L2 acquisition and processing. The volumetric decreases are known to begin in the 20's or later, indicating that if there were a link between brain volume and L2A, it would clearly be biological in nature, but not maturational.

In vivo studies using MRI reveal that, as a general rule, brain volume decreases with advancing age (see Raz, 2005, for a review). The degree of shrinkage varies from brain structure to brain structure, as do the details of timing of the onset of decline. In all cases surveyed, the declines once begun are typically linear and are consistently continuous, with no leveling-off at the end .

Starting at the coarsest level of investigation, *in vivo* studies reveal that gray matter volume declines in a linear fashion beginning in childhood (e.g., Pfefferbaum et al., 1994; Courchesne et al., 2000). (Postmortem studies reveal a slightly different trajectory; see Miller, Alston & Corsellis, 1980; cited in Raz, 2005) In contrast, white matter volume enjoys a linear increase until the early 20's. An ensuing plateau continues into the 60's, after which there is a linear decline into old age. The inverted U shape for white matter volume over age has been replicated in many but not all studies. Declines are minimized in healthy subjects, and heightened in subjects with cardio-vascular disease (Raz, 2005, p. 22).

Looking now at specific regions of interest (ROI), the question driving a great deal of research is whether the volumes of some areas of the brain are more affected by age than others. The answer to this question is not straightforward, as differing results are obtained by different measurement techniques and in longitudinal and cross-sectional studies, with the latter typically underestimating the amount of shrinkage. However, a reasonably clear picture of age-related declines in regional brain volumes is offered by Raz (2005) in his survey of relevant studies. Results of cross-sectional studies reveal that the sites most affected by age are the prefrontal cortex, the putamen, the caudate, the hippocampus, and the temporal cortex. In longitudinal studies, we find that the four areas most susceptible to volumetric declines are the entorhinal cortex, the hippocampus, the caudate nucleus, and the frontal lobe, all with $\geq 1\%$ annual declines.

In addition to these data, we consider the results of the Raz et al. (2003) study of 53 healthy adults between the ages of 20 and 77 years. Focusing on the striatum, the researchers found that the caudate nucleus volume declined at .83% per year, the putamen .73% per year, and the globus pallidus at .51% per year. The shrinkage began in young adulthood. The observed declines were also linear, that is, the same rate of decline was observed for younger and older subjects. These volume declines in the striatal region go hand in hand with dopamine declines in this area (see Issue #11).

Most studies, however, do not reveal the epochs at which declines begin and at which the slopes are most dramatic. However, Raz (2005) sifts through the relevant studies to come to a few generalizations about timing and geometry of declines. First, volumes of the caudate, cerebellum and cortical structures decline in a linear fashion that starts in adolescence and continues throughout the lifespan. Second, the entorhinal cortex and

hippocampus appear to incur a greater annual shrinkage than other areas of the brain. However, according to Raz, these declines tend to begin in middle age to old age in the case of the hippocampus, and only in older age for the entorhinal cortex.

We conclude this section with two basic observations. First, the volumetric changes are not confined to a period. This lack of boundedness is consistent with other evidence of age effects operating across the age spectrum. Secondly, in the neocortical areas, the timing of volumetric declines parallels the timetable of effects in cognitive tasks associated with those brain structures; as suggested earlier, these cognitive operations underlie production and acquisition in the L2. However, for the medial temporal areas, volumetric declines are not necessarily synchronized with performance declines in episodic/associative (declarative) memory (Reuter-Lorenz, 2000, pp. 101ff.), which is essential to connectionist accounts of language acquisition and use and to the representation and processing of irregular forms under the words-and-rules approach (e.g., Pinker & Ullman, 2002) in both L1 and L2 (Ullman, 2001). In other words, neural resources, for which volume is a proxy, are better predictors of associated performance in some brain areas than others. Clearly, the underlying nature of this discrepancy warrants further exploration.

ISSUE #11: Age, dopamine systems, and L2A. The role of the nigrostriatal dopamine (DA) system in efficient motoric function is well known. In addition, DA appears to be involved in certain higher-order cognitive functions, many of which are implicated in language learning and language processing—such as attention, motoric sequencing, and working memory (for a review, see Bäckman & Farde, 2005).

Schumann (1997, 2001) and colleagues (Schumann et al., 2004) have argued that DA is involved in basal ganglia functions in L2A, some of which are implicated in motivation to learn and learning reinforcement. These mechanisms are thought to contribute to proceduralization, i.e., the creation and strengthening of linguistic rules (Lee, 2004, pp. 66-67). The results of the study by Teichmann et al. (in press) of Huntington Disease patients reinforce the notion that the striatum is involved in the processing of rules as opposed to words. Crosson et al. (2003) argue for a role of the basal ganglia in a variety of language production processes at the levels of syntax, lexicon, and phonology. For additional studies of BG involvement in language processing, see Friederici and Kotz (in press), Moro et al. (2001), Newman et al. (2001), and Ullman (under revision).

DA is likewise considered essential to defossilization, an un-doing of automatized non-targetlike linguistic performance (Lee, 2004, pp. 68-71). Arguably, similar processes that are mediated by DA are also involved in minimizing L1 influence. For example, one could envision the role of DA in suppressing and supplanting L1 routines in syntax (e.g., association of Noun-first clausal sequences with Subject-initial canonical word order, when in fact the L2 is canonical word order is Object-initial) and routines in phonology (e.g., the representation of aspirate and non-aspirate stops as allophones, as in English, when the L2 represents them as separate phonemes, as in Korean).

In humans, D1 and D2 receptors are distributed throughout the neocortex, with especially dense innervation in the caudate and putamen of the striatum. Damage to the DA system in humans results in deficits in executive function, verbal fluency, and perceptual speed. In rodent and monkey studies, destruction of dopaminergic pathways in the mesocorticolimbic system produces memory impairments and attentional deficits.

Lesioning these pathways in the subthalamic nucleus results in deficits in attention, executive function, and motor sequencing. Pharmacological interventions in humans show increased performance on tasks that measure information processing speed, discrimination, and working memory. Both D1 and D2 receptors appear to be implicated in working memory modulation. Models of DA function converge on the notion that DA facilitates switching between attentional targets both within and between neural networks, with the effect of enhancing the ratio of incoming neural signal to background noise. For a review of effects on cognition of age-related changes in nigrostriatal DA, see Bäckman and Farde (2005).

Li, Lindenberger and Sikstrom (2001) find that declines in dopamine D2 receptors begin in the early 20's and continue across the lifespan. These declines are observed not only in the basal ganglia, but also in the hippocampal structures, frontal cortex, anterior cingulate cortex, and amygdala. Of particular interest is the suggestion by Li, Lindenberger and Sikström (2001), that with increased age and DA loss, neural noise increases, resulting in less-distinctive neural representations. This decrease is linked to age-related cognitive deficits across domains such as working memory and executive function (Bäckman & Farde, 2005, p. 61.)

A few PET studies have looked at age-related declines in DA markers and associated cognitive declines. A familiar pattern of results emerges from these studies: declines begin in early 20's and continue linearly throughout the lifespan. A representative study is that of Volkow et al. (1998), who determined by PET the striatal D2 binding potential in adults aged 24 to 86 years. Behavioral measures included executive, motoric and perceptual speed. D2 receptor binding decreased with advancing age in the caudate ($r=$

-.62) and putamen ($r = -.7$); similar correlations were obtained between age and task performance.

Thus, with respect to the geometry and timing of the DA age gradient, and in terms of the cognitive functions mediated by DA, it would appear that DA declines are a plausible mechanism (among others) underlying age effects in L2 acquisition and processing. A similar conclusion could apply to stress- and age-related increases in cortisol, which have been linked to hippocampal atrophy (Lupien et al., 1994, 1998). And, with adjustments in the temporal and geometric features of the age-related declines, the same may be said of fluctuations in estrogen levels over age, as forms of this hormone are known to mediate verbal memory, production, and processing (e.g., Resnick & Maki, 2001; Kimura, 1995). As was the case with respect to brain volume declines, the possible linkage to L2A of changes in dopamine, estrogen/testosterone, and acetylcholine metabolism (e.g., Freeman & Gibson, 1988) is understood to be biological in nature, but given that the changes do not begin until adulthood, a maturational explanation is ruled out.

WHAT IS THE NATURE OF AGE EFFECTS IN L2A?

The overarching issue explored in this contribution is the nature of age effects in L2A. L2A research seeks an understanding of the underlying causal mechanisms—biological and experiential—as well as mediating factors—endogenous and exogenous.

Candidate explanations for age effects in L2A are not in short supply. Singleton (in press) sees no less than 14 versions of the Critical Period Hypothesis as it applies to L2A (CPH/L2A). Birdsong (1999) cites 6 major variants of the CPH/L2A and points to numerous endogenous and exogenous factors that affect ultimate attainment in L2A.

MacWhinney (in press) identifies 10 “concrete proposals” in the literature that relate AoA to ultimate L2A attainment, and to these adds two explanations for variability in L2A outcomes.

In the literature, the hypothesized mechanisms underlying age effects in L2A relate to the biology of the species (in its neurobiological or neurocognitive dimensions), developmental aspects of cognition, experience in language use, or psycho-social/affective dimensions of individuals’ personalities. Below these accounts are listed and classified.

Neurobiological

Lateralization (Lenneberg, 1967, inter alia)

Neural commitment / plasticity (Lenneberg, 1967, inter alia)

Functional localization (Seliger, 1978)

Maturation of brain cells (Diller, 1981)

Metabolic bottoming-out / Use it then lose it (Pinker, 1994)

Myelination (Pulvermüller & Schumann, 1994)

Neurocognitive

Physical and cognitive aging (Bialystok, inter alia)

Post-pubertal changes in cognition (Krashen, 1975; Rosansky, 1975; Felix, 1981; Bley-Vroman, 1989)

Weakened declarative memory for irregular forms (Birdsong, 2005)

Decline in implicit learning ability (DeKeyser, 2000; 2003a,b)

Cognitive-developmental

Decline of access to UG (various)

Decline in ability to set parameters in UG (various)

Natural selection (Hurford & Kirby, 1999)

Use it or lose it (Bever, 1981)

Less is more (Newport, 1990)

Affective

Strengthening of affective filter (Krashen, 1985)

Hardening of ego boundaries (Guiora 1972, 1992; Taylor, 1974)

Psycho-social distancing plus declining motivation (Schumann, 1978a,b; 2004; see also
Moyer, 2004; Piller, 2002)

Experiential

L1 - L2 reciprocal influence (various)

L1 entrenchment leading to processing interference (Elman, 1996; Kuhl, 2000; Marchman,
1993; MacWhinney, 2002)

L1 entrenchment + L2 parasitic on L1 (Hernandez, Li & MacWhinney, 2005;
MacWhinney, in press)

It is recognized that some of these presumed factors and mechanisms are not consistent with research findings. We have considered in this paper, for example, the problematics of maturational accounts. We know also that implicit memory/learning processes (often

considered synonymous with procedural memory/learning processes) are relatively unaffected by age (Craig & Jennings, 1992; Park & Shaw, 1992), clashing with DeKeyser's contention (DeKeyser, 2000; 2003a,b) that implicit linguistic knowledge cannot be acquired past puberty.³ Adding to these doubts are electrophysiological and hemodynamic data that suggest that implicit learning is represented neurologically in the absence of explicit performance correlates (Indefrey et al., 2005; Osterhout, 2004). The Less is More Hypothesis has received mixed support, with evidence both pro (Elman 1993; Goldowsky & Newport, 1993; Pitts Cochran, McDonald & Parault, 1999) and contra (Fletcher, Mayberry & Bennett 2000; Ludden & Gupta, 2000; Rohde & Plaut, 1999, 2003). Certain accounts that emphasize biology over other factors and which predict zero or little incidence of nativelikeness (e.g., Hyltenstam & Abrahamsson, 2000, 2003; Johnson & Newport, 1989; Long, 1990) are compromised by both the sizable incidence of nativelike performance, as well as by demonstrations that some quite challenging aspects of L2 processing are trainable (Bradlow et al., 1997; McClelland, Fies, & McCandliss, 2002).

Just as ill advised as putting uncritical faith in a misguided account is an exclusive focus on a single mechanism or type of mechanism. Some accounts of underlying causes of age effects in L2A and processing isolate a single mechanism, or focus on one type of mechanism. Yet this practice often simplifies the phenomena in question and polarizes stances on an extremely textured set of issues. It is arguably more reasonable to take the initial position that the identified factors and mechanisms that are not at odds with empirical findings are each at work in some fashion in L2A. Some may account for more variance than others, and individual differences in L2 attainment and processing are to be expected.

While much of the emphasis in age-related research in L2A has been on biological mechanisms, we must avoid placing too much of the explanatory burden on biology. For example, an adult learner might be neurobiologically endowed for learning an L2 but fall short of nativelikeness for lack of personal interest in passing for a native (Piller, 2002). It is important also to remember that biologically-based mechanisms are not necessarily maturational in nature.

The complex nature of L2 acquisition and processing, along with the range of individual differences in outcome, cries out for explanatory synthesis, for clear-eyed and open-minded attempts to integrate biological, cognitive, experiential, linguistic, and affective dimensions. It is hoped that the facts and issues discussed here can prompt further investigations into the multiple causes, mechanisms, and factors that are implicated not only in the general decline of ultimate L2 attainment over AoA, but also in the impressive rate of nativelikeness and near-nativelikeness among late-starting L2 learners.

NOTES

- 1 These figures are expressed as absolute values because some experiments correlate AoA with numbers of errors or degree of foreign accent—thus yielding positive correlation coefficients—while others correlate AoA with numbers of correct items or degree of nativelylike accent—thus yielding negative correlations.

- 2 The hypothesis of a critical period for L2A has been formulated by different researchers in different ways, and invoking a variety of explanatory mechanisms; see the final section of this paper as well as Birdsong (1999), Singleton (in press), and Singleton and Ryan (2004) for overviews.

- 3 To clarify, it is understood that implicit/procedural memory is little affected by aging. However, it is likely that with age it takes longer to transfer knowledge to procedural memory, leading to delays in automatization and skill acquisition (Charness & Campbell, 1988; Charness & Bosman, 1990; Clarys, Isgingrini & Haerty, 2000; Fisk & Rogers, 1991).

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