Foreign Language Anxiety: Translating cognitive neuroscience to the classroom

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Highlights for "The neural networks of language development"

Educators are looking at the wrong level.

We cannot easily link macro behaviour with brain structures (synapses or hemispheres).

Cognitive analyses can connect education (behavior) to systems neuroscience.

Cognitive analyses are already helpful for improving educational practice.

Abstract

Foreign Language Anxiety (FLA) is an obstacle for second language learners including Chinese undergraduates speaking English in China, Hong Kong and abroad. A neurobiological model of FLA is presented here that has a focus on Electrodermal Activity and the hypothalamic pituitary adrenal (HPA) axis. Evidence from fMRI shows that highly anxious undergraduates in Beijing show greater deactivation in the ventral anterior cingulate cortex and stronger activity in the left superior temporal gyrus and left precentral gyrus reading English nouns and less activity of the ventral striatum and stronger activity of left superior temporal gyrus, right superior frontal gyrus, right middle frontal gyrus and right cuneus during generation of English verbs. A new hypothesis about second language learning and neural activity is proposed. Specifically, the results suggest that high FLA participants recruit motivational networks more than participants with low FLA.

We know that language experience shapes the human brain in fundamental ways. Since ancient times (e.g. Valerius Maximus 14 AD to 37 AD), philosophers have marvelled at the link between damage to the brain and language processing (Benton, 1967). However, advances in brain technology have changed how we view the neurobiology of language processing resulting in a vast range of research studies and theories (Hagoort & Indefrey, 2014; Poeppel et al., 2010), and the emergence of learned societies, and scholarly works (Hickock & Small, 2015). A majority of this research has been concerned with the neurobiological constraints on learning a second language and the neurobiological consequences of bilingualism.

Bilingual and monolingual speakers differ in gray matter volume (GMV) (Mechelli et al., 2004; Bialystok et al., 2012, Abutalebi et al. 2012; Abutalebi et al. 2013) and white matter microstructure as measured by Diffusion Tensor Imaging (DTI) reflecting neuroplasticity due to lifelong bilingual language experience (Luk et al. 2011; Singh et al., 2017). Turning to language learning, numerous studies show that GMV can be altered by learning a foreign language e.g. see *Neuropsychologia* (special issue on Language Learning) (doi: 10.1016/j.neuropsychologia.2017.01.008). For example, there is an increase in cortical thickness for simultaneous interpretation trainees after completion of a postgraduate degree in conference interpreting (Hervais-Adelman et al. 2017; also Elmer et al., 2011; Martensson et al. 2012). Similarly, white-matter tracts change after language training including in the direct pathway connecting the posterior superior temporal gyrus to the anterior part of the inferior frontal gyrus (Hickok & Poeppel, 2004, 2007) as well as an indirect pathway connecting the inferior parietal cortex to the anterior language cortices (Catani, Jones & Ffytche, 2005). For example, Hosoda et al. (2013) report that language training produces an increase in structural connectivity between the inferior frontal gyrus and the caudate nucleus and Qi et al. (2015) report that foreign language training (native English speakers learning Mandarin) and increased language proficiency after new learning is associated with changes to white matter structures in studies of native English speakers (see also Schlegel et al., 2012; Zatorre, Fields & Johansen-Berg, 2012).

Scientific knowledge about the cognitive neuroscience of foreign language learning is founded on themes uncovered by studies of the neural representation of language, language acquisition, and language use. Such themes draw on scientific disciplines that reflect the history of cognitive neuroscience including artificial intelligence (AI), computational modelling, information processing, linguistics, neuropsychology and neuropathology. Much has been learned and many debates have been largely settled in the field over the past twenty years mostly due to integration of advanced methods in brain imaging. The next frontier is to reconcile the neuroscience of language with microstructures in the brain at biochemical and cellular levels. To date, there is little known about the interaction between neurochemistry and language learning. The purpose of this chapter is to initiate a discussion about how neurobiology constraints second language learning. The initiative owes much to the pioneers of studies of native and second language acquisition (Patricia Kuhl, Janet Werker) that revealed an interplay between neurobiology and language experience focusing first on changes in auditory, visual, and multimodal perception in the first months of life to the developmental trajectory of speech comprehension and production that are constrained by the timing of neuroplasticity including cortical microcircuits and effective connectivity that is linked to critical periods and epigenesis. For example, work by Hansch and Werker (2015) translates findings from animal models of cortical plasticity using a neurotransmitter called Gamma-aminobutyric acid (GABA: an inhibitory neurotransmitter) by linking GABA to known critical periods for perceptual plasticity of speech sounds and subsequent language development. This is the first attempt to articulate how neurobiology constrains native and non-native language acquisition at a molecular level (see also Woo et al., 2017). The proposal here is that acquisition of a non-native language can be linked to these neurobiological constraints albeit via a little known link connecting anxiety to language acquisition. The conceptual link is founded upon an effect called *Foreign Language Anxiety* (FLA) a well described impediment to learning in environments where the medium of instruction (MoI) is the not native language i.e. English. The new conceptualisation of links between FLA, neurobiology and science of learning a language seems *prima facie* to be of value.

Foreign Language Anxiety (FLA)

Anxiety is generated by arousal of the autonomic nervous system (ANS). It is accompanied by subjective feelings of tension, apprehension, nervousness, and worry. Anxiety can be regarded as both a state and a trait reflecting the long debate around the causal factors of behavior in clinical psychology (Spielberger, 1972). FLA and - by extension - Second Language Anxiety (SLA) are defined as the fear or apprehension experienced when a language learner or language user is required to perform in a non-native language situation (state) (Dewaele Petrides & Furnham, 2008). FLA can also be considered a type of linguistic insecurity that is linked to any situation where the goal of the speaker is to rise within the social scale of the dominant language environment (Labov, 2006; Sevinç, 2017). Models of trait FLA are less developed and most likely depend on a range of (state) factors including exposure to second language use, demands given the sociocultural context (age, gender, status) and predisposition due to life experiences (poverty). It is not known whether FLA when conceptualised as a trait can be distinguished from these state variables.

Models of FLA do however locate effects on behavior and learning at an individual (psychological) level. For example, cognitive appraisal is assumed to play the function of orienting the self to a potential threat. Communicating in a non-native language in the classroom can induce a threat to self-esteem within power structures triggering physiological effects have been verified with subjective) (self report) and objective (skin conductance) recordings. In most 'state' accounts, FLA is determined by cross-linguistic contact in power structures that are determined socially by variability in age, dialect, gender, student-teacher status and socioeconomic class (Sevinç, 2017). However, we do know that situation specific FLA is mediated by neurobiological states and these have measurable physiological correlates (Levenson, 2014) e.g. FLA is manifest as physical changes via the ANS tremors, rapid heart palpitations, sweaty palms, gastrointestinal discomfort and blushing that are coordinated by certain parts of the CNS (Croft et al. 2004; Sevinç 2017).

Studies show that just as monolingual speakers show CNS changes via electrodermal biomarkers such as skin conductance level (SCL) while public speaking (Croft, Gonsalvez, Gander, Lechem, & Barry, 2014), second language users demonstrate FLA in similar situations but, critically, show more widespread FLA in a range of situations e.g. when examined in a second language (Gregersen, Macintyre, & Meza, 2014). Indeed, FLA is reported in classrooms around the world (for Spanish see Levine, 2003; Coryell & Clark, 2009; Tallon, 2009, 2011; Chinese, Xiao & Wong, 2014; Korean, Jee, 2016; Arabic, Elmahjoubi, 2011; Odeh, 2014). Some studies report a negative relationship between FLA and second language achievement although this relationship is definitely not linear (Dewaele, 2007). Reflecting the Yerkes–Dodson (1908) law there is a positive relationship between arousal and performance, but only up to a plateau upon which the relationship becomes negative i.e. there appears to be an inverted U shaped relationship between FLA and performance. Studies with tertiary Hong Kong pupils who are learning in English as the MOI support this conjecture (Weekes, 2017) although this can vary according to pupil gender (see Figures 1A and 1B).

Insert Figures 1A and 1B here

MacIntyre (2017) systematically reviewed the literature on FLA and proposed classification of the causes and effects of FLA as deriving from academic, cognitive and social variables. However, causes of FLA are not independent from one another and similarly the observed responses (anatomical, behavioural and psychological are not different). For instance, one possible cognitive cause of FLA—e.g. fear of losing a sense of identity—could be linked to social causes that are determined by power structures in the testing environment such as the status of the language in use and the proficiency of the interlocutor (teacher). Such related academic and cognitive causes are also intertwined with socially embedded factors such as gender and status which are in turn linked to embarrassment during social interaction, in classrooms and examinations (Sevinç, 2017). Perhaps unsurprisingly therefore, studies report associations between FLA, age (Dewaele, 2007), gender, education, second language use (Onwuegbuzie et al., 1999) and proficiency (Santos et al., 2015). Although these random variables could be considered 'traits', this is not meaningful. Very few studies have considered these relationships when measured outside the learning environment. For example, if the MoI is the dominant (by status) but not the native language - what implications does this have for pedagogy more generally? Certainly it is true that language skills in the non-native language may be delayed (literacy and vocabulary). But what of other subjects taught in the non-native language such as maths, science and technology? The relationships between gender and FLA are also not clear yet potentially revealing for assessments and school based policies. Dewaele (2007) reported no difference between females and males in FLA for pupils learning a second language (not always using an MOI that is a non-native language). However, there is a persistent trend for studies to find that female pupils are more anxious than males (Abu-Rabia, 2004; Dewaele & MacIntyre, 2014; though see Weekes, 2017). There is also debate over whether self reported language acquisition (AoA) interacts with FLA. Dewaele et al. (2008) claim that the earlier a language is acquired, the lower FLA (though see Sevinc, 2017) at least in second language learners. Frequent exposure to a second language reduces FLA but is correlated with linguistic achievement, proficiency and self-confidence (Baker & MacIntyre, 2000 (Dewaele, 2007).

There is substantial evidence to support the hypothesis that FLA has a wide impact on learning using a non-native MOI. Gregerson et al. (2014) reported that students who are not anxious when using a second language nevertheless experience greater FLA in evaluative situations specifically in classroom settings. Classroom settings may raise FLA for a variety of reasons. Lower proficiency could increase frustration in the communication of known concepts and vocabulary (in the native language). Perceived confidence in the use of a second language in scholastic contexts may diminish when the vocabulary is specific to a domain of learning e.g. neuroanatomy (see Weekes, 2017). If errors/negative feedback has consequences for assessment, progression and qualification (as when learning exclusively via English at the University of Hong Kong), this can have escalating effects on FLA leading to a vicious downward cycle. It is notable that throughout East Asia, English is used as the MOI by *teachers who are not native English speakers*. These endogenous, psychological or 'trait' factors need to be positioned within the socio-cultural context. MacIntyre and Serroul (2015) call attention to the power relationships in such situations particularly if the interlocutor (teacher) is a native speaker in the MoI (English) but the student is not although this extends to situations within which the interlocutor is a non-native speaker in the MoI. Perceived status in these situations is be a critical determinant of FLA regardless of other random variables. Furthermore, when the MoI is the language of achievement within the socio-cultural context (as it nearly always is), there is even greater potential for FLA to circumvent new learning across all school subjects. The secondary effects of FLA post-instruction include lower self-confidence, self-esteem and social participation causing further avoidance of the anxiety-provoking language (Gregersen 2003). FLA might then diminish proficiency in the second language and contribute to effects on performance, leading to a negative feedback loop linking behavioural avoidance, 'competence', mobility and opportunity (see Horwitz, Horwitz, & Cope, 1986).

Theoretical models of FLA increasingly recognise the multiplicity of variables that can lead to FLA. For example, MacIntyre's Dynamic Approach (2017) argues that FLA should be studied as a complex of the language and socioemotional experiences that link a learner to specific situational circumstances, as well as individual differences in *physiological reaction*, linguistic ability, self-related appraisals, interpersonal relationships, and socio-cultural context surrounding the learner and interlocutor (MacIntyre & Serroul, 2015). In this account, FLA is viewed as a self-reflection on language experience including the learner perceptions, situational circumstances and other intra-individual (random) factors. To test this account, it is useful to use an objective method to separate the subjective experience of FLA from the physiological effects of FLA to achieve a fully explanatory account. Figure Two summarizes the factors that potentially contribute to FLA when learning new (domain) words acquired in a non-native language. This model has been tested in Hong Kong where students learn vocabulary in a curriculum using a MoI that is non-native.

Insert Figure Two here

FLA and the Science of Learning: A case study from China

An enduring problem in studies of FLA is lack of methodological rigour. Dewaele et al. (2008) argue that self-rated perceptions of FLA are too subjective and thus cannot reveal cause and effect of the processes underlying FLA across varying situations. The reasons include circularity of logic when testing models of FLA e.g. if a speaker is anxious about using L2 in a classroom, they may underestimate a number of self rated factors such as AoA, frequency of use or proficiency simply due to poorer self-evaluations whereas a less anxious pupil may overestimate the same variables. Little progress can be made using self-report measures alone. In post-colonial Hong Kong, English remains the language of achievement and success. It is also the MoI at the most sought after schools most particularly in the tertiary sector. Learning English is a therefore a highly valued goal, leading to mobility and status and there is much at stake for students who are both learning English as a second language and who are taught in non-native English as the MoI. When faced with an expectation to excel in oral and written examinations in English, Hong Kong students experience extraordinarily high levels of FLA in their interaction with instructors who are typically native English speakers (Walker, 1996). However, even when the instructor and student share the same language (Cantonese), the requirement to learn and to teach in English is no different. Social facilitation theory assumes that the status of a native speaking teacher will be higher than a non-native speaking instructor and the resulting power imbalance can hinder the performance of both pupil and teacher in the non-native language due to FLA (Geen, 1989). One compelling question therefore is whether communication with a native (Cantonese) speaking teacher decreases or increases FLA in typical tertiary learning environments?

Studies in Hong Kong show that FLA can improve learning up to a point but too much diminishes gains. Early studies of FLA (in the second language classroom) in Hong Kong were all based on self-report and little work had been done on objective markers of FLA in second language classrooms or in classrooms where English is the MoI. Recent work (Weekes, 2017) has pushed the outstanding questions in the field further by introducing science of learning to the study of FLA in the typical classroom at the University of Hong Kong. Furthermore, including reliable biomarkers of FLA has enhanced interpretation of cognitive variables previously known to contribute to learning domain word vocabularies in a non-native language (see Weekes, 2017) and by extension to the effects of FLA (see Figure Two). To summarise, methodology designed to measure the physiological changes associated with Foreign Language Anxiety (electrodermal activity, electroencephalogy, salivary cortisol, skin conductance), has been able to validate the experience of FLA with more precision than self-report measures. However, questions remain. For example, relative status between interlocutors has an influence on FLA (Sevinç, 2017), leading to inequality in classrooms. We know that sociolinguistic imbalances between interlocutors increases FLA e.g. interlocutors will evaluate and correct non-native speech spontaneously. Cognitive, social and linguistic factors may therefore lead to greater FLA and hence manifest biomarkers more if the instructors are native speakers of an MoI compared to examiners who are non-native speakers. Furthermore, the unequal power relationships for female students when speaking to male teachers also has an impact on FLA (Piller & Pavlenko, 2009; Sharma, 2011). Therefore, it can be expected that FLA will be higher if the examiner is in a dominant power relationship e.g. a male English speaking instructor.

The complexity of FLA is reflected in the multiple forms of measurement of emotional states and stress. There are at least three valid methods to measure anxiety: behavioral observation or ratings; physiological assessment such as heart rate or blood pressure; and self-report i.e. feelings and impressions are recorded. FLA is typically measured via self-report in second language classrooms e.g. records in diaries, observed in focus groups and group interviews, recorded in surveys, or third party observations. However, objective data to validate FLA in these studies has been lacking (de Bot, Lowie & Verspoor, 2007). As argued above, gender has a potential effect on FLA albeit for reasons of social status rather than biological sex per se. However, there may be some gender differences in learning new vocabulary (Fitch et al., 1993).

Scovel (1978) was first to review the literature on relationships between anxiety and second language learning. Scovel distinguished state anxiety as a response to stress-provoking stimuli e.g. public speaking and trait anxiety as a personality trait that varies across individuals. Scovel (1978) argued that the subjective experience of FLA should be validated physiologically using biomarkers. Despite early calls for such research, few studies have taken up this challenge. In early studies, Horwitz, et al developed a self-report Foreign Language Classroom Anxiety scale (FLCAS). A weakness of the FLCAS however is that it was conceptualized for second language learning situations specifically and may not generalise to other classroom settings. It has also been criticised for assuming that FLA is a situation-specific-construct only making it a limited tool for use beyond the second language classroom setting (Sevinç, 2016, 2017). For example, in a classic study, MacIntyre and Gardner (1989) reported a curvilinear relationship between self reported levels from FLCAS and second language proficiency in a second language classroom. They reasoned that if FLA is a debilitating condition, then verbal fluency and grammatical knowledge should be reduced given greater FLA (see also Côté, 2017 for a recent study). Several studies from Hong Kong supported this prediction (Tsui, 1996; Walker, 1996). However, these data are difficult to interpret without consideration of socio-cultural factors. For example, studies show a *positive* relationship between FLA and the number of years of learning English i.e. FLA *increases* as proficiency improves (Walker, 1996; also Saito & Sammy, 1996). This suggests that for Hong Kong students, demands placed on using English with more years of experience in tertiary settings (more use of non-native MoI) does not diminish FLA as in does in second language learning. There are other methodological limitations with prior studies. Firstly, all studies are cross-sectional therefore it is an open question whether FLA is a cause or a consequence of performance. Secondly, studies focus on oral language proficiency and neglect written language entirely which is most likely to define academic success. Third, self-report questionnaires (FLCAS) do not control for demand characteristics. Finally, little is known about FLA when the MOI is a non-native language across a wide range of learning domains (as is found in all prestigious secondary schools in Hong Kong).

Liu et al. (2018) report on the brain mechanism and the neural bases of FLA modulating the process of language production in behavioral experiments and two fMRI experiments. Two groups of subjects were selected from 280 undergraduates using the FLCAS (Foreign Language Classroom Anxiety Scale): a high anxious and a low anxious group. Their results show that the high anxious group has a higher heart rate when reading English nouns and verbs. In addition, the fMRI activity of the left superior temporal gyrus and left precentral gyrus was greater in the high anxious group than low anxious group. Furthermore, the high anxious group had greater deactivation in the ventral anterior cingulate cortex compared to the low anxious group. There was a linear correlation between FLA scores and deactivation in the ventral anterior cingulate cortex when reading in English but not in reading Chinese and a linear correlation between fMRI activation in ventral anterior cingulate cortex, left superior temporal gyrus and left precentral gyrus when generating an action from an a visually presented object in English but not in Chinese. The results also show that the high anxious group has less activity in the ventral striatum than the low anxious group in English verb generation. We suggest that greater activity for high anxious participants in left superior temporal gyrus, right superior frontal gyrus, right middle frontal gyrus and right cuneus suggests greater demands on the language and attentional networks. A negative correlation between activity in the ventral striatum and this network suggest an interaction between brain areas related with language processing and brain regions related to emotional functions; which indicates FLA is specific type of endogenous anxiety.

Current work in China

To enter a tertiary course at a Hong Kong university, students are expected to attain near native levels of literacy (not speech) in a range of academic subjects and are then required to study in English as the MoI. The self-reported experience of Hong Kong students points to high levels of FLA and subsequently stress because they are expected to first achieve superior levels of proficiency in a non-native language and then achieve superior levels of academic performance in a non-native language. Within Asian cultures, gender differences in FLA are also reported (see Park & French, 2013; Mahmood & Iqbal, 2010). However, the findings are contradictory and do not necessarily imply that female pupils are any more predisposed to FLA than male pupils (Weekes & Ferraro, 2011; Weekes, 2017). Current studies using a physiological measurement of FLA with a wearable device that measures the extent of electrodermal activity are used in Hong Kong classrooms during the learning of written words. Electrodermal activity is widely used in psychophysiology to estimate levels of state anxiety (Dawson, Schell, & Filion, 2007). Electrodermal activity is an ideal index of variation in electrical characteristics of the skin (Boucsein 2012) and wearable devices record skin conductance response (SCR), and skin conductance level (SCL). Skin conductance is an indication of psychological and physiological arousal. Skin conductance increases with sweating. The sympathetic branch of ANS controls sweating activity. Skin conductance is therefore a measure of sympathetic nervous system (SNS) responses. Woodrow (2006) reported that SNS activity such as increased heart and perspiration rates, dry mouth, muscle contractions, and sweaty palms increase during observations taken in a second language classroom and also noted behavioral phenomena such as class avoidance, preoccupation on performance of others, not completing assignments on time and general lack of motivation for learning (Sevinç, 2017). It is apparent from interviews with (non-native speaking) instructors from the University of Hong Kong (Vice-President of Teaching and Learning Amy Tsui,

2017) and focus groups at other institutions that FLA is evident in many classrooms.

Electrodermal activity has at least two measurable components: (1) skin conductance level (SCL) and skin conductance response (SCR) (Dawson et al., 2007). SCL is one characteristic of the electrodermal activity signal and it is related to slower-acting components, to the overall level of activation, and smaller rises or declinations recorded over an extended period of time (Eilola & Havelka, 2011). According to Gilissen et al. (2007), SCL reflects changes in autonomic arousal associated with emotional reactivity, fear and stress whereas SCR refers to the specific and faster changing elements of the signal in relation to presented stimuli at a phasic level (Braithwaite et al., 2015). SCR occurs within 1-1.5sec following appearance of the stimulus, and may last for 2-6 seconds. In contrast, SCR, the phasic component of the electrodermal activity, refers to the specific and faster changing elements of the signal in relation to stimuli presented (Braithwaite et al., 2015). Knight and Borden (1979) report that the anticipation of public speaking led to increased SCL and Moore and Baron (1983) suggest SCR reflects a motivational process associated with stress in monolingual speakers, whereas SCL reflects cognitive processing. Geen (1989) also reports more spontaneous SCRs in the presence of an observer than when the participant was alone suggesting a social effect.

Croft et al. (2004) found that SCL correlates with increases in arousal during the anticipation of public speaking for monolingual speakers with a significant decrease upon completion. Conversely, the speech act itself is related to cardiac activity. Such results highlight distinctions between cardiac and measures of electrodermal activity and suggest that they can be measured independently in research on FLA. Sevinç (2017) evaluated FLA using measures of FLA for the first time in bilingual speakers during a video-retelling task. A language background questionnaire recorded information on AoA, proficiency, frequency of language use and other variables such as level of education. She found that SCLs and SCRs were correlated with FLA self-report. Higher levels of SCL/SCRs were also negatively correlated with proficiency and frequency of use of the heritage language (Turkish). These results confirmed the feasibility of recording physiological biomarkers with self-reports of FLA and were the first evidence of relationships between FLA and autonomic arousal.

CORT and FLA

Research in neuroscience reveals a negative impact of anxiety in brain circuitry that is related to learning, memory and executive functions (Vogel & Schwabe, 2016). Animal models show a correlation between new learning (inhibition, navigation, spatial skills) with measures of stress such as cortisol (CORT) and other biological indices (Tang et al., 2014). Anxiety is also a modifying variable in models of learning and memory at the neurochemical level. Less is known about the contribution of CORT to language learning and more specifically learning vocabulary when the MoI is a second language. We know anxiety affects memory for new learning (Vogel & Schwabe, 2016) and that the formation of new memories - long-term potentiation - is optimal when glucocorticoid levels are elevated (Lupien et al (2007). Lupien et al. (2007) reported significant decreases in LTP after exogenous glucocorticoid administration (high GC state) and also after adrenalectomy (low GC state). Lupien et al. (2007) also showed that a novel, unpredictable and uncontrollable learning context causes a stress response if it is perceived as self-threatening i.e. given a negative evaluation by a learner. Crucially, relationships are time-dependent, impairing memory retrieval and the acquisition of information encoded after a stressful event while enhancing new memory formation around the time of a stressful encounter.

We found evidence that the learning of expert words in a neuroanatomy curriculum at the University of Hong Kong (Weekes, 2017) is related to electrodermal activity and self ratings of FLA. The results show that differences in cognitive (memory) components of executive function and memory for serial order predict acquisition of vocabulary in English. Specifically, inhibition measured with a verbal Stroop task explains a significant amount of variation in new word learning. In this paradigm, Hong Kong students learn new words during the first year of study. All stimuli are late acquired low frequency words so that possible effects of extant vocabulary knowledge on new learning are minimized. Domain words are taken from curricula and form a corpus of 300 words that are unfamiliar to native Cantonese speakers. Knowledge of the words before learning is assessed via a lexical decision task and writing to dictation task. Results show that inhibition, number of hours of study and individual differences in nonverbal IQ predict new word learning. Female students reported more hours of study than male students consistent with findings from PISA (2003 and 2012) and girls report more anxiety than boys despite better new learning of domain words overall. Using the Horowitz (1986) scale modified for Hong Kong students (Walker, 1996) the results also show female students report higher FAS than male students despite outperforming boys on a test of word knowledge. Such data suggest that (1) late acquisition of domain words is more successful for females than males in Hong Kong and (2) FAS predicts domain word learning in female Hong Kong students when the MoI is English. To validate results, electrodermal activity is measured in the same group and variability across learning trials via electrodermal activity is recorded with a wearable device. Pilot results show that electrodermal activity levels drop towards the end of each trial but electrodermal activity is higher when more words needed to be written. In addition, males are far more variable in electrodermal activity than females. One limitation of the results is that if the participants are aware of the goals of the study, it is possible that demand characteristics influence FLA measurement. Furthermore, status of the teacher (age, gender, native language) has not been manipulated experimentally. Although electrodermal activity has been validated with objective measures of circulating cortisol using mouth swab and, there are difficulties recording CORT reliably in baseline and experimental conditions. This is a limitation as the long term goal is to link electrodermal activity, FLA and other measures of stress to the neurochemistry of anxiety and learning. Although reasonably successful in animal models, such studies have proven hard to implement in human participants particularly with underage subjects such as secondary school pupils. Therefore, an additional measure is under development using a more reliable measure of cortisol (CORT) based on the methodology developed by Tang et al. (2014). This methodology relies on establishing a baseline during the early waking hours, measurements at rest and then also in experimentally controlled situations such as in an examination room, learning environment or in classrooms with confederates and in-vivo instruction.

Next steps in neurobiological modelling of FLA

Animal studies show that new learning and LTP is associated with the hypothalamic-pituitary-adrenal (HPA) axis (Tang et al. 2012, 2014), which is reflected in both the basal and stress-evoked corticosterone (CORT-E) responses. For example, the context of a novelty-induced facilitation (disinhibition) is reflected in a low-basal CORT-E and a high-evoked CORT-E profile (see further discussion below Tang et al. 2011, 2014). In terms of the model in Figure One, the hypotheses are: that FLA as measured by CORTE, electrodermal activity, and stress report will influence learning of expert words; FLA effects will interact with status in learning. To test these hypotheses, electrodermal activity and CORTE measures will be used as an objective biomarker of FAS that is validated with subjective ratings. Although we know FLA is associated with learning words in Hong Kong students, the neurobiological mechanisms are unknown. Therefore we plan to identify biomarkers underlying the relationship between FLA, cognition, gender and word learning by adding effects of electrodermal activity and CORTE into a multivariate model. We expect cortisol measures of FLA to explain additional variance in learning performance that is independent of FLA, language background variables (AoA, proficiency, frequency of use), cognition (IQ, attention, working memory) and electrodermal activity. We also expect these effects will interact with student gender and native language of the instructor. It is expected that electrodermal activity levels will be higher (1) in females than males; (2) if the examiner is male; and (3) if the examiner is a native speaker of English and (4) highest if the examiner is a male native speaker of English. Students from the University of Hong Kong are recruited at the beginning of first year of study. Measures of electrodermal activity, circulating cortisol, self reported FLA, language background, cognitive and verbal abilities of students are assessed. Groups of students are then randomly assigned to an oral exam condition to be given at the end of Year 1. Group 1 is tested on the definition of new words with a native English speaking male instructor; Group 2 is tested by a native Cantonese speaker (male instructor); Group 3 is tested by a native English speaking female instructor; and Group 4 by a Cantonese female instructor. Samples of saliva cortisol are taken prior to, during, and after a learning tasks. We will therefore collect saliva samples independently of the oral exam at two times (a) at the trough of the cortisol circadian cycle and again shortly after awakening to estimate parameters characterizing HPA functions. This innovative approach translates insights from animal research to humans (Tang et al., 2014). Specifically, we will be obtaining a measure of cortisol regulation at a time separated from tasks wherein situational CORTE will be sampled. To validate results to spoken language performance, students are asked to complete an oral dictation task. A pretest cortisol measure is collected before sleep and within 5 minutes after the participant wakes by obtaining repeated saliva samples (Tang et al., 2014). Change in cortisol levels are computed by [(post-sleep–pre-sleep) / pre-sleep]. Electrodermal activity measures are taken during tasks. In Phase 2, done after 12 months, participants are presented with an examination requiring a definition of expert words in English. All other procedures are identical to Phase 1. Task-related changes in cortisol levels are measured before oral exam and 5 minutes after oral exam. Change of task-related cortisol levels are computed using the formula [(during-task – pre-task)/pre-task]. Electrodermal activity measures are taken during the examination. A Biopac system with a module for skin conductanceand cardiovascular activity (PPG100C) is also used (Sevinç, 2017). During all phases, self report levels of FLA are tested with a 5-point Likert scale (Sevinç, 2017).

Following Sevinç (2017), the analysis of electrodermal activity data is performed with AcqKnowledge 4.1 software. First, data is cleaned, as movements can alter electrodermal activity signals. For the SCL, the background tonic electrodermal activity, can differ between individuals. Therefore a relative value is derived to test for changes in SCL during experimental manipulations. The SCL signal contains SCRs, which elevate the measure (Boucsein, 2012). Therefore, the amplitudes of SCRs will be subtracted from the tonic signal (SCL) to establish a reliable measure of background SCL. A change in mean SCL scores is calculated relative to the mean baseline for each phase for each individual. To test the predictions, comparisons are made between gender and the native language of the instructor. The mean amplitude and frequency of SCL and SCR in native and non-native modes is subtracted from each first and then from the male and female interlocutors. After subtractions, higher SCL and SCR values are considered to signify tonic and phasic levels of secretion (Dawson et al., 2007). In addition to Biopac, a wearable device is used to record electrodermal activity (Figure 2). The Empatica E4 wristband records and uploads electrodermal activity, GSR, Blood Volume Pulse, Acceleration, Heart Rate and Temperature on a secure platform and shows real-time physiological data acquisition and software for later analysis and visualization https://www.empatica.com/en-eu/research/e4/. A measure of basal CORT (CORTB) (Tang et al. 2012) is also used. Tang et al. (2012) defines CORTB as a sample obtained in an undisturbed state. Participants are awakened at a predetermined time with a reminder to collect a sample from the bed without rising. Participants carry out their normal daily routine. CORTS is a stress-evoked measure that captures the rising phase of the CORT response to measure one's ability to mount a rise in response to the start of the daily activity. CORTS is defined as the percentage of CORT increase relative to CORTB within 5 and 15 min of waking and rising from the bed. An evoked CORT response, CORT-E, is defined as the difference between CORTS and CORTB normalized by CORTB CORT-E = (CORTS − CORTB)/CORTB × 100.

Both samples will be brought to the lab for further processing on the morning of the testing session. CORT-E is a measure of trait as opposed to a state cortisol as it reflects the ability of a participant to regulate the level of circulating stress hormone.

Towards a neurobiological model of FLA

A connection between hippocampal activity and language learning has been long established. Opitz and Friederici (2003) proposed the hippocampal system and the prefrontal cortex as the neural mechanism underlying grammar learning. Mårtensson et al. (2012) showed that adult foreign-language acquisition drives increases in cortical thickness and hippocampal volume of novice interpreters before and after three months of intense language studies. Results revealed an increase in hippocampus volume and in cortical thickness of the left middle frontal gyrus, inferior frontal gyrus, and superior temporal gyrus for interpreters relative to multilingual controls. Such findings show that changes to the hippocampus reflect foreign-language acquisition. It is not clear however what neurochemical changes explain these changes. One hypothesis is that the hypothalamic-pituitary-adrenal (HPA) axis mediates language learning which is reflected in the basal and stress-evoked corticosterone (CORT-E) responses (Tang et al. 2014). Testing this hypothesis offers a novel way to bridge education, gender, learning, mental health, neurobiology and wellbeing. A short-term goal is to extend models of expert word learning (Figure 1) to the neurobiological level when MoI is a non-native language thus creating considerable anxiety and stress in the classroom. In the long term, this neurobiological model could be translated into anxiety reduction techniques to enhance learning in second language classrooms particularly not exclusively when MoI is a non-native language.

According to Tang et al. neonatal exposure to stress has an impact on hippocampal synaptic plasticity via corticosterone modulation (Tang & Zou, 2001). They found that early life experience also preferentially enhances the effect of stress hormones on synaptic plasticity in the right hippocampus (cf., Mårtensson). A right-sided enhancement in long-term potentiation suggests a greater potential for synaptic modification necessary for the encoding of new information in the right hippocampus. A right-sided enhancement in the sensitivity to corticosterone modulation allows the activity and plasticity within the right hippocampus to be more effectively regulated by corticosterone during stress (FLA). Inhibition of excessive excitation and long-term potentiation by corticosterone during FLA can minimize potentiation of synaptic strength due to non-task related stress-triggered activation, this prevents stress from interfering with task learning. Asymmetric protection from the detrimental effect of excessive stress could potentially be the cause of enhanced memory functions subserved by the right hippocampus. Tang and colleagues recently proposed a hippocampal theory of language lateralization and behavioral, neuroanatomical, neurophysiological, and pharmacological data to confirm a subset of hypotheses that constitute the neurobiological theory of FLA.

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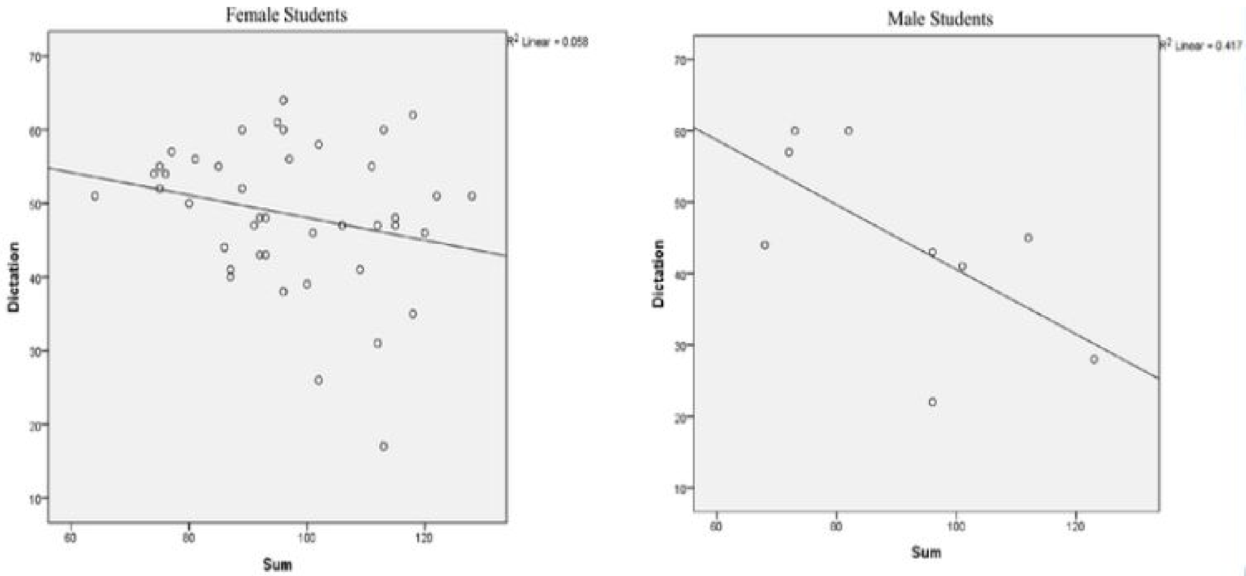

Figure 1: Correlation between Dictation and FLA in female and males students

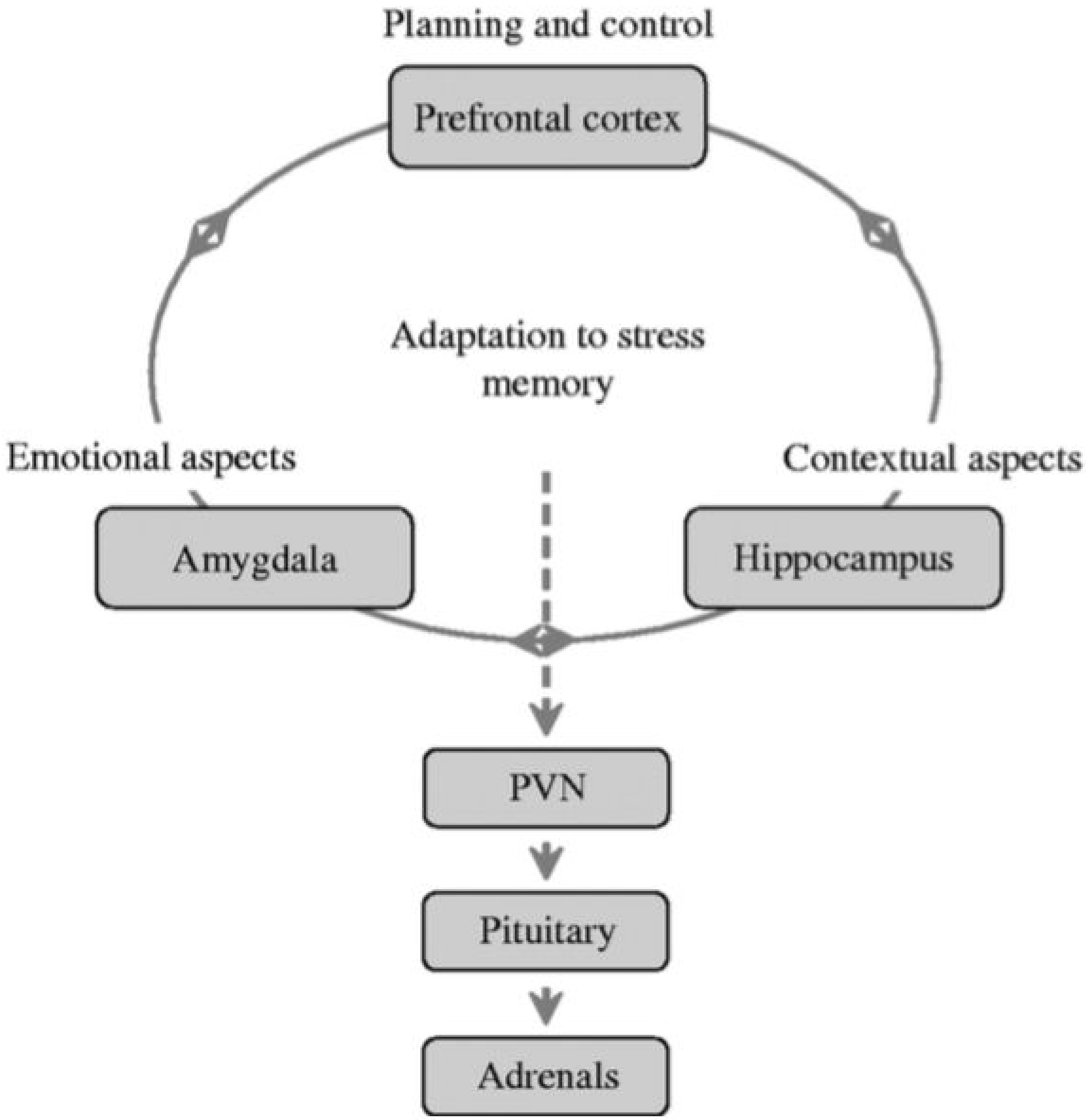

Figure 2 Model of FLA and new word learning

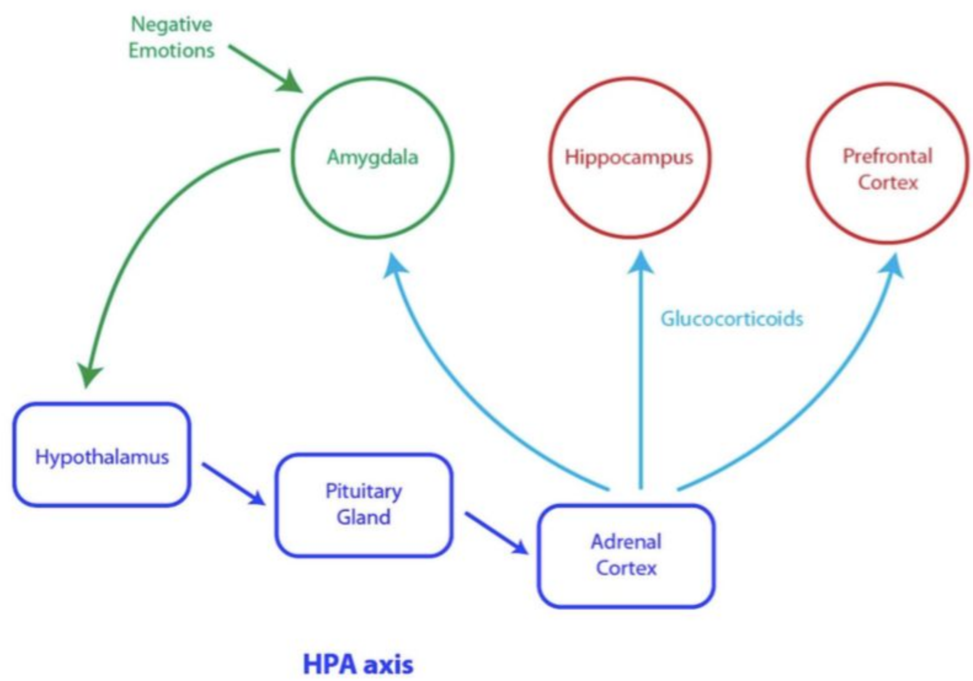

Figure 3 The Hypothalamic Pituitary Adrenal (HPA) axis and Foreign Language Anxiety (FLA)