Using Online Word Games to Study Language Comprehension Skills across the Lifespan

Overview of Research Question

The ability to communicate using language is a core human ability that provides the foundation for social, educational and professional aspects of society. Language allows us to rapidly transfer ideas from the mind of the speaker/writer to the mind of the listener/reader. This transfer relies on the ability of the readers and listener to quickly decode the meaning of each word that they hear: they must make continuous/ongoing 'best guesses' about the intended meaning of each word.

Children and adults with poor language comprehension skills are known to be disadvantaged throughout their lives, in terms of both academic attainment and occupational status. It is therefore vital that we understand why, how and when individual differences in language comprehension arise in order to develop more effective school-based interventions and improve outcomes for children who may otherwise struggle to understand complex spoken and written language. This project will use web-based language games to systematically explore how these language comprehension skills develop across the lifespan.

This project focuses specifically on a key aspect of language comprehension: the ability to rapidly and accurately access the meanings of words within sentences. Decoding the meanings of words is made more difficult by the presence of 'lexical ambiguity': words whose spoken (or written) form can refer to more than one concept. For example when decoding the sentence "What an enormous trunk!" the listener must work out whether the speaker was referring to an elephant's nose, a large suitcase, a car's boot, or the main stem of a tree.

The need to accurately and rapidly disambiguate word meanings is vital for communication: approximately 80% of common words have multiple dictionary definitions[1]. Take for example the first sentence of the text given to 11-year-old children across England as part of the national Key Stage 2 reading comprehension assessment[2]: "Dawn was casting spun-gold threads across a rosy sky over Sawubona game reserve". The words in this sentence have on average 8.8 dictionary definitions: children must, for example, work out that "Dawn" does not refer to a girl's name and that "game" does not refer to a competitive sport.

While many of us are able to accurately disambiguate most words without effort, research has revealed large individual differences in this skill: those who perform poorly on general tests of comprehension skill have been shown to be both slower and less accurate at retrieving the meanings of words[3]. Unfortunately, poor *language* comprehension skills also put children at significant risk for developing *reading* difficulties[4] that can persist throughout the lifespan and have measurable long-term impact on both academic attainment and occupational status[5].

The aim of the project is to establish the specific cognitive factors that contribute to individual differences in comprehension skill across the lifespan, with specific focus on (i) lexical quality, (ii) executive control and (iii) working memory. This will be done using online, fun language games. Versions of these games will be developed for both children and adults.

The Role of 'Lexical Quality' in Word Meaning Access

We define lexical quality as the extent to which a word's mental representation contains accurate and comprehensive information about its spelling, sound and meaning[6]. This factor is closely associated with comprehension success: high quality lexical representations not only afford efficient word recognition (i.e., knowing *which* word was present), but also ensure

that appropriate stored knowledge about each word becomes available for higher-level comprehension processes.

Existing evidence confirms the view that lexical quality (as measured by vocabulary tests) is important for rapid and accurate processing of ambiguous words[7,8] The most likely explanation for this strong relationship is that vocabulary tests of crystallised knowledge provide an index of the quality of lexical-semantic knowledge: high quality lexical knowledge is needed to know rare words such as "palliate", and also to process highly familiar words such as "JAM" rapidly and effectively within sentence contexts. Under this view, lexical knowledge is not an 'all or nothing' factor in which words are either known or unknown: even for highly familiar words there is significant variation (both within and across individuals) in lexical quality, and this variation impacts directly on the ease with which word meanings are processed.

The Role of Executive Control (EC) and Working Memory (WM) in Word Meaning Access

Lexical quality is unlikely to be the sole factor that determines an individual's comprehension skill. Evidence from neuroimaging, transcranial magnetic stimulation and neuropsychology provide convergent evidence that the left inferior frontal gyrus (LIFG) is critically important for comprehending high-ambiguity sentences[9]. There is a widespread consensus that this region does *not* contain stored lexical-semantic knowledge, but instead supports cognitive control processes that operate on these representations. Specifically, the influential "conflict resolution account"[10] argues that the LIFG is required to resolve competition between activated representations (for both linguistic and non-linguistic stimuli). These 'semantic selection' processes are particularly important to resolve the conflict that arises when a strongly dominant meaning is inconsistent with the sentence context (e.g., "the sheep was in the PEN"), or when equally likely meanings are both consistent with a relatively neutral context (e.g., "he mentioned the ORGAN")[9]. These views predicts that individuals' abilities to understand ambiguous word will be closely related to their performance on other EC tasks that load heavily on selection/inhibition (e.g., Stroop[11]).

An alternative view is that the LIFG provides the WM support needed for earlier parts of a sentence to be recalled and reprocessed, for example when prior context is needed to process an ambiguous word, or when subsequent information indicates that an ambiguous word was initially misinterpreted (e.g., "the PEN was used to enclose sheep")[12]. This view predicts that the ability to comprehend ambiguous sentences will be closely related to an individual's performance on other WM tasks.

Existing evidence[8] is equivocal on the issue of how domain general executive skills relate to disambiguation skills in healthy adults. Although we have observed a significant correlation between participants' ambiguity resolution performance and measures of both EC and WM, these effects were not significant when differences in vocabulary knowledge were taken into account. Larger scale studies are therefore needed.

Aims of the Current Project

To develop fun language games that can be played on phones and tablets by both children and adults that provide reliable measures of individuals':

- Sentence comprehension skill
- lexical quality (i.e. vocabulary knowledge)
- executive control (EC)
- working memory (WM)

By measuring how individual differences in disambiguation performance relate to tests of lexical quality, EC and WM, we will assess the extent to which comprehension, at different ages, is limited by development of these key skills.

Key Characteristics of the Games

We will develop innovative experimental tools for assessing individuals' abilities to process various aspects of language. These tasks will be fun and engaging. Web-based data

collection methods will be developed to facilitate recruitment from relatively large and diverse population samples. By characterising these tasks as 'games' and ensuring the suitable reward/feedback mechanisms within the game (e.g., collecting tokens and unlocking achievements) we will make it possible to collect data from far more participants and from more diverse populations than is usually possible with conventional lab-based approaches. **It is this aspect of the project for which the training and expertise provided by Cauldron will be essential.**

Outline of Games

The overall language game will comprise four separate mini-games that will each assess an individuals' skill at the specific cognitive components mentioned above. By combining these mini-games into an overall game and ensuring that each of the mini-games must be completed for maximum reward (tokens and achievements) we hope to obtain data from significant number of individuals on all four mini-games. We aim to recruit a total of 1000 'complete' participants but hope that social media coverage may allow us to substantially exceed this target. Each mini game will be piloted separately with performance being compared to more conventional language assessments prior to rolling out the final version of the game.

While the details of the Mini Games will be developed by the student in collaboration with both their academic supervisors and Cauldron, we outline here a possible task that could be used to provide measures of lexical quality (i.e. vocabulary knowledge).

Participants will see a single target word (e.g., HAPPY) followed by a string of possible matches that occur in random locations. The participants game is to select as quickly as possible any word that are a close match in meaning with the target word before they disappear from the screen (e.g., DELIGHTED, CHEERFUL). These words will appear for random durations, with mean duration reducing across blocks as participants perform better. On some trials the matches will use the most frequent meaning/sense of the word, while on others the participant will have to find matches with words that are ambiguous and where the relevant meaning is NOT the most frequent (e.g., BANK – SHORE). By systematically varying both the frequency of the words and the relative frequencies of the word meanings, we can obtain both measure of:

(i) Vocabulary depth: A high score reflects good basic knowledge of relatively rare words
(ii) Flexibility in vocabulary access: A high score reflects the ability to extract the contextually relevant meaning of words

Other fun games will then be developed to measure sentence comprehension (matching sentences with appropriate pictures), working memory (recalling words/symbols that are interleaved with other challenging puzzles) and executive control (e.g., Stroop).

Timeline

Months 1-3 (UCL): Finalise outline plan for the different mini-games
Months 4-15 (Cauldron):

- Develop necessary coding skills
- Implement the mini games in Gorilla
- Collect pilot data to ensure feasibility and improve playability

Months 16-23 (UCL)

- Collect pilot data alongside well established language processing tests to ensure validity and reliability of each mini game

Months 23-36 (UCL)

- Pilot complete game (target 50 complete data sets)
- Improve mini-games in response to pilot data
- Roll out complete game (target of 1000 complete data sets)
- Analyse data using Logistic Mixed Effects Modelling

Possible Findings

We anticipate replicating the finding that vocabulary knowledge is strongly correlated with disambiguation skill. In contrast, theoretical accounts predict that EC and/or WM should contribute to disambiguation skill, but this is not well supported by current evidence.
In addition, the large, varied group of participants will also allow us to test interactions between these factors, for instance that effects of EC and WM may be larger in low-vocabulary individuals. In addition, it is likely that these effects/interactions will vary with participant age, especially amongst older participants.

Dissemination Plan
Communication of our results to the scientific community will be achieved through publication in high quality journals (e.g., Cognitive Psychology, Cognition, Journal of Memory and Language) and via presentations at appropriate national and international conferences (Experimental Psychology Society, Psychonomic Society, European Society for Cognitive Psychology). Publications will be Open Access to ensure our findings are readily available in the public domain.
Findings will also be shared with the wider community and relevant stakeholders so as to provide opportunities for dissemination and interactive discussion between research and practice. Prof Norbury has excellent links to educational practitioners and a strong track record of organising events to facilitate dissemination to relevant groups (e.g., http://www.socialcommunicationworkshop.com/).

Summary
This project will contribute to our understanding of the cognitive mechanisms that support language comprehension by revealing patterns of individual differences in key cognitive functions and how these vary across the lifespan.

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