Cognition 143 (2015) 178–186

Contents lists available at ScienceDirect

Cognition

journal homepage: www.elsevier.com/locate/COGNIT

Deconstructing phonological tasks: The contribution of stimulus and response type to the prediction of early decoding skills ☆

Anna J. Cunningham [a,1], Caroline Witton [a,b], Joel B. Talcott [a,b], Adrian P. Burgess [a,b], Laura R. Shapiro [a,*]

[a] School of Life and Health Sciences, Psychology, Aston University, UK
[b] School of Life and Health Sciences, Aston Brain Centre, Aston University, UK

ARTICLE INFO

Article history:
Received 6 August 2014
Revised 19 June 2015
Accepted 26 June 2015
Available online 10 July 2015

Keywords:
Phonological awareness
Decoding
Task
Reading
Measurement
Latent variable modelling

ABSTRACT

Phonological tasks are highly predictive of reading development but their complexity obscures the underlying mechanisms driving this association. There are three key components hypothesised to drive the relationship between phonological tasks and reading; (a) the linguistic nature of the stimuli, (b) the phonological complexity of the stimuli, and (c) the production of a verbal response. We isolated the contribution of the stimulus and response components separately through the creation of latent variables to represent specially designed tasks that were matched for procedure. These tasks were administered to 570 6 to 7-year-old children along with standardised tests of regular word and non-word reading. A structural equation model, where tasks were grouped according to stimulus, revealed that the linguistic nature and the phonological complexity of the stimulus predicted unique variance in decoding, over and above matched comparison tasks without these components. An alternative model, grouped according to response mode, showed that the production of a verbal response was a unique predictor of decoding beyond matched tasks without a verbal response. In summary, we found that multiple factors contributed to reading development, supporting multivariate models over those that prioritize single factors. More broadly, we demonstrate the value of combining matched task designs with latent variable modelling to deconstruct the components of complex tasks.

1. Introduction

Although performance on tasks of phonological processing is strongly predictive of early reading (e.g. Melby-Lervag, Lyster, & Hulme, 2012), the underlying cognitive mechanisms that drive these relationships remain the subject of debate. One source of uncertainty is the complexity of phonological tasks, with many cognitive components potentially driving the associations with reading (as discussed by Bowey, 2007; Protopapas, 2014; Ramus & Ahissar, 2012; Snowling, Chiat, & Hulme, 1991). Take, for example, three classic measures of phonological skill that have been found to be highly predictive of children's reading achievement; phoneme isolation (e.g. 'what is the first sound in *san*?'; Lervag, Braten, & Hulme, 2009; Puolakanaho et al., 2007), phoneme deletion (e.g. 'what is *san* without the *s*?' Hulme, Bowyer-Crane, Carroll, Duff, & Snowling, 2012; Muter, Hulme, Snowling, & Stevenson, 2004), and nonword repetition (e.g. 'say *san*'; de Jong, 1998; Nation & Hulme, 2011). Each of these tasks share three key features: (a) the linguistic nature of the stimuli (which are usually words or pseudowords), (b) the phonological complexity of the stimuli (words can be segmented into phonemes), and (c) the response mode (which is nearly always by verbal report). In addition, there are demands on attention, short-term and working memory, and the ability to understand instructions during task execution. Since performance variability can result from the effect of any one, or combinations of these factors, it is typically not possible to discern the contributions of specific components. Of course, the issue of task complexity extends beyond reading research, and similar discussions have arisen in many areas of cognition (e.g., working memory, Conway et al., 2005; executive function, Hughes, 2011; language in relation to Theory of Mind, Milligan, Astington, & Dack, 2007).

The current study aimed to address these methodological and measurement issues by isolating the unique contribution of

☆ This study was supported by the Economic and Social Research Council (ESRC, ES/H031685/1; PI Laura Shapiro). We are immensely grateful for the support and participation of the staff and pupils at the schools. Thanks go to the Research Assistants from Aston University who collected the data; http://www.aston.ac.uk/alp/.

* Corresponding author at: School of Life and Health Sciences, Psychology, Aston University, Aston Triangle, Birmingham B4 7ET, UK.
E-mail address: l.r.shapiro@aston.ac.uk (L.R. Shapiro).
[1] Present address: Centre for Research in Psychology, Behaviour and Achievement, Coventry University, Coventry CV1 5FB, UK.

http://dx.doi.org/10.1016/j.cognition.2015.06.013
0010-0277/

stimulus and response mode respectively to the prediction of early decoding skills, while controlling as closely as possible for auxiliary task demands. This was achieved by using sets of carefully matched tasks as indicators for latent variables representing each component, and by partialing out memory and non-verbal reasoning ability.

1.1. Solutions to the problem of task complexity

A standard approach to disentangling complex tasks within cognitive psychology is to compare matched tasks with a common procedure. For example, Vandermosten et al. (2011) isolated the linguistic component of categorical perception tasks by comparing performance on a common task involving speech vs. non-speech stimuli matched for temporal cues (see Banai & Ahissar, 2006; Groth, Lachmann, Riecker, Muthmann, & Steinbrink, 2011 for similar paradigms). Another example comes from Majerus, Linden, Mulder, Meulemans, and Peters (2004), who isolated the role of sublexical knowledge on verbal short-term memory by comparing tasks using illegal vs. legal nonwords matched for procedure. These types of matched task designs are a fruitful way to examine the relative influences of different aspects of complex tasks. However, the studies relied on individual tasks to measure each construct and used relatively small samples. Outcomes may therefore be affected by heterogeneity in their samples, test sensitivity and method variance.

In contrast, latent variable modelling, or factor analysis (as exemplified in Ramus, Marshall, Rosen, & van der Lely, 2013) enables a more accurate estimate of an underlying skill by representing the commonalities among a range of measures, and extracting idiosyncratic task-specific factors as error variance. Additionally, structural equation modelling enables the correlations between latent variables to be explicitly modelled, providing an estimate of the unique contribution of each factor on an outcome (Byrne, 2010; Tabachnik & Fidell, 2007). Many studies on the role of phonological skills in reading development have used latent variable approaches (see Bowey, 2007 for a review). Nevertheless, the use of latent variables does not necessarily lead to a purer measure of each construct. Instead, the meaning of each latent variable is tied to the choice of indicators (measured variables) and the predictive power of each latent variable may depend on whether additional task demands are balanced equally between different constructs. In particular, the predictive power of a broad latent variable encompassing classic phonological tasks may be exacerbated by the breadth of skills they challenge (e.g. working memory, attention).

We propose that the role of specific components of complex tasks can be isolated using matched task designs in combination with latent variable modelling. For example, tasks can be created that follow a common procedure but vary in one crucial aspect (e.g., the response type: verbal or pointing using a touch screen). These closely matched tasks can then be used as indicators for correlated, but distinct latent variables (e.g., 'verbal response' and 'non-verbal response'). The uniqueness of the component (in this case the verbal response) is extracted by the latent variable and then linked to an outcome (in this case decoding) using structural equation modelling. As the tasks vary along only one dimension, auxiliary demands are controlled for as closely as possible through the covariance between the factors (e.g., see Kane et al., 2004 for a similar approach in the context of working memory).

1.2. The current study

The goal of the present study was to investigate the importance of three fundamental components of phonological tasks in the prediction of early decoding skills: The first two related to stimulus (the linguistic nature and phonological complexity of the stimulus) and the third concerned response mode (verbal response).

A large sample of 6 to 7-year-old children (UK Year 2) was tested in order to capture an intermediate stage of reading development when phonological skills are most critical (Ehri, 2005). Decoding (regular and pseudoword reading) was used as the outcome measure as phonological processing more directly impacts on the reading proficiency of phonologically transparent items (Snow & Juel, 2007).

The classic tasks of phoneme isolation, deletion and nonword repetition were used as templates for four sets of novel tasks created through the systematic manipulation of stimulus type and response requirement; (1) tones with a non-verbal response (non-linguistic, non-verbal), (2) phonemes with a non-verbal response (linguistic, non-verbal), (3) phonemes with a verbal response (linguistic, verbal), and (4) pseudowords with a verbal response (phonologically complex, verbal). Tones with a verbal response were not included as pilot studies indicated that children could not reliably provide a verbal response to tonal stimuli. Similarly, pseudowords with a non-verbal response were not included as these tasks could not be matched in procedure to our other non-verbal response tasks. The consequences of using a design that was not full-factorial are explained in the discussion.

All twelve tasks were used as indicators for latent variables/factors that defined specific task components. We initially built a full model that combined both stimulus and response factors. However, it was not possible to calculate as extremely high correlations between factors (multicollinearity) caused by each task loading on both a stimulus and response factor meant that they could not be reliably separated in the prediction of decoding (see Rigdon, 1995 for a discussion). Therefore, we tested two alternative models of our measures, structured either by stimulus or by response. The Stimulus model began with a tone factor (task-set 1), while the addition of a phoneme factor (task sets 2 and 3) represented the contribution of simple linguistic stimuli, and the addition of a pseudoword factor (task set 4) represented the contribution of complex linguistic stimuli to the prediction of decoding skills. Auxillary task demands (such as understanding of instructions, attention and working memory load) were represented by the tone factor, leaving only stimulus-specific contributions to be made from the phoneme and pseudoword factors. The Response model began with a non-verbal response factor (task-sets 1 and 2), and the addition of the verbal response factor (task sets 3 and 4) represented the contribution of a verbal response. In both cases, the effects of verbal and visual-spatial short-term memory, and non-verbal reasoning were partialed out.

1.3. Predictions

All phonological theories of reading implicate the processing of phonological (linguistic) stimuli as central to the relationship with reading (Ramus & Szenkovits, 2008; Snowling & Hulme, 1994). In addition, reading requires one to create and store accurate representations of speech units (words or pseudowords) comprising a series of segments (Snowling, 2000; Snowling & Hulme, 1994). Therefore, we predict that both the linguistic nature and the phonological complexity of the stimuli in phonological tasks should drive the prediction of reading. In contrast, there is disagreement over whether giving a verbal response is critical. Research suggests that phonological tasks requiring a non-verbal response predict reading to a similar degree as those requiring a verbal response (e.g., Gayan & Olson, 2003; Hulslander et al., 2004). However, the measures in these studies were not matched for the length of stimuli or processing demands, so a direct comparison of response type was not possible. However, other research has shown that paired associate learning tasks that required a