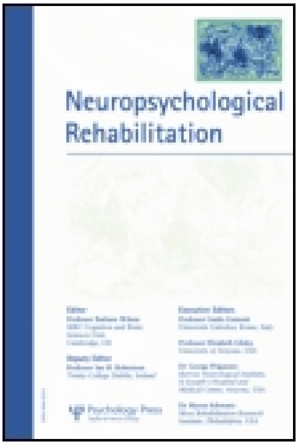

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Overview and ways forward for future research

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Overview and ways forward for future research

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This Special Issue of *Neuropsychological Rehabilitation* on errorless learning in rehabilitation of language and memory impairments includes one review and six empirical studies, which present new clinical findings evaluating the effectiveness of errorless learning as an intervention method for people whose symptoms stem from different neurological aetiologies. These studies delineate some of the critical theoretical–clinical issues through which we might optimise learning and rehabilitative efforts more fully.

Keywords: Errorless learning; Rehabilitation; Aphasia; Amnesia.

THE CRITICAL REVIEW

Middleton and Schwartz open this Special Issue with some thought-provoking and challenging arguments that provide a powerful critique of certain assumptions relating to errorless learning. They begin with first principles. Errorless learning is clearly a form of learning defined by exclusion; i.e., eliminating or at least markedly reducing the occurrence of errors during learning, wherein a correct sequence of behaviours is reinforced as the appropriate response to a given stimulus (Fillingham, Hodgson, Sage, & Lambon Ralph, 2003). By implication, the reduction of errors necessitates

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that the learning task is relatively easy to accomplish. In its implementation, therefore, errorless learning becomes, in part, the absence of difficulty. But what is sacrificed by ensuring the absence of difficulty? Middleton and Schwartz have collated considerable evidence suggesting that, within the non-clinical domain, the requirement to practise retrieval from long-term memory (for example, from phonological-semantic representations for word retrieval) is the most significant determinant of effective learning and contrasts with the short-term memory stores called upon by "easy" learning tasks such as word repetition. This viewpoint is reinforced by the related findings that other conditions which promote effective learning (for example, expanding schedules of learning over time) make retrieval harder, not easier.

The crux of the argument made by these authors is either reinforced or weakened by the view that is taken of the relationship between non-clinical and clinical learning. One example of a specific point on which non-clinical versus clinical learning may diverge is the issue of learning without successful word generation in word learning paradigms. Middleton and Schwartz note two compelling findings from the non-clinical learning literature. The effects of retrieval practice are most robust and long-lasting when retrieval is effortful yet successful, i.e., "desirably difficult" (Bjork, 1994). However, there are benefits to the testing of learning beyond successful retrieval; i.e., testing, in and of itself, leads to better recall of target information (e.g., Kornell, Hays, & Bjork, 2009; Nickels, 2002; Roediger & Karpicke, 2006). Yet, even within the current, relatively limited, clinical errorless learning literature, there are reported findings which appear to contradict this argument. McKissock and Ward (2007) directly compared errorless learning in anomic picture naming with two errorful conditions: errorful-feedback, in which participants were encouraged to guess a picture name and were told if they were unsuccessful, and if so, given the target word to repeat; and, errorful, in which participants attempted naming with no feedback as to accuracy. McKissock and Ward found that, while errorless and errorful feedback conditions were both effective (with the errorless condition yielding the numerically greater accuracy scores), errorful (no feedback) was similar to a no treatment control condition. Essentially, naming practice without external support, such as feedback and target modelling, was of no help at all to these participants with anomia. Fillingham, Sage, and Lambon Ralph (2005a) also directly compared errorless and errorful without feedback conditions in an earlier study. However, in this method, while explicit feedback was withheld, there remained implicit feedback to participants in that progressive cues continued to be offered until correct production was achieved. Their study, therefore, does not run counter to the contention from McKissock and Ward that, for aphasic picture naming, no benefits to testing of learning, without successful retrieval, were observed.

Within the clinical domain, Middleton and Schwartz have made the refreshingly heretical suggestion that decreasing cues treatment should be considered an errorful method, given the probability of inducing errors. They go further to propose that this method be removed from the errorless learning evidence base and highlighted as an example of the virtue of error generation. Despite its plausibility, this contention is problematic. Ideally, decreasing cue procedures should represent the optimal interaction of low error and high effort (Komatsu, Mimura, Kato, Wakamatsu, & Kashima, 2000) by commencing with easy, highly supportive learning tasks (e.g., word repetition in a lexical retrieval task) which gradually reduce external support such that more independent task completion is achieved. For example, in Conroy and Scowcroft, decreasing cues were applied to naming sets of nouns and verbs. Within a training session, these cues decreased from initial whole word repetition, to part-word phonemic cues, to no cue on the last presentation of each item within that session. Decreasing cues should more accurately be referred to as a staircase method (Abel, Schultz, Radermacher, Willmes, & Huber, 2005; Conroy, Sage, & Lambon Ralph, 2009a; Glisky, Schacter, & Tulving, 1986) in which cues start at the top (optimally supportive) level and then gradually climb down each step for as long as success in the task is maintained. The cue level increases again, however, if an error is produced.

Decreasing cues have generally been construed as a variant on errorless learning because of this painstaking step-by-step method intended to minimise errors whilst ensuring sustained effort. However, as the decreasing cue method may allow for production of errors (Riley & Heaton, 2000), it clearly deviates from a pure errorless one. Middleton and Schwartz take this observation a step further and argue that, given this tolerance of error production, the decreasing cue method prioritises retrieval practice over error avoidance. But the staircase of decreasing (and, as necessary, increasing) cues more closely represents repeated accessing of short-term memory stores (albeit with fading primes) rather than retrieval practice from long-term memory. Hence, the decreasing cues method is typically a relatively unchallenging training task, quite a distance from the degree of "desirable difficulty" required for retrieval practice.

Error introduction into the decreasing cues method does pose a conceptual challenge for a learning paradigm defined by the avoidance of errors. Essentially, this becomes an empirical question as to how many correct versus erroneous productions have occurred in a specific study. The follow-on question is what proportion of errorlessness still ensures a purported errorless benefit. Even with non-clinical participants, error production in an errorless paradigm is likely, although this may be only to a small degree. This effect, however, will be amplified within the clinical domain. So, once we accept that error production will not be at 0% within an errorless learning method, the question becomes what is the outer limit for error-production: 10% (nine correct productions for every one error), or 20% (four correct productions for every one error) and so on? Arguably, one could go as low as 33% (two correct productions for every one error) and make the Hebbian case that, in such a learning method, twice as many correct behaviours cancelled out any risks of error-reinforcement. As Middleton and Schwartz advised, "Ultimately, the value of errorless learning approaches will be more accurately described if empirical rates of errors – rather than subjective determinations – are used to firmly establish a treatment as errorless or errorful". Such empirical specification will be the first step to investigating the critical degree of errorlessness which may confer benefit in clinical learning paradigms (and, indeed, this is why from the initial studies of Fillingham et al. we have always reported the per session accuracy rates).

Overall, the Middleton and Schwartz review reminds us that there are several key learning principles, some of which may cause a tension with the necessity of ease of task within errorless learning. One way to achieve greater clarity as to the interaction of differing learning principles will be through increased precision in our empirical research projects, especially where we are investigating the optimal tension between competing learning principles.

ERRORLESS LEARNING AND MEMORY REHABILITATION

The studies which describe interventions within the domain of memory in this special issue also continue the theme of bridging between clinical and non-clinical learning. Specifically, the distinction between the two populations is somewhat blurred by Anderson et al.'s study which focuses on frontal lobe (FL) and medial temporal lobe (MTL) functioning in the non-clinical elderly population. Anderson et al. made a convincing case for an MTL locus for the errorless learning advantage. That is, the errorless advantage appears to emerge as we move down the range of skills within the non-clinical population towards the upper end of the clinical population. This gives us a sense that the concept of "desirable difficulty" may interact with some degree of depletion of learning resources, whether because of non-clinical poorer MTL functioning or clinical amnesia. This theme echoes with earlier non-clinical errorless learning studies (e.g., McCandliss, Fiez, Protopapas, Conway, & McClelland, 2002) that found an errorless advantage for Japanese speakers trying to distinguish between /r/ and /l/ in rhyming words such as "rock" – "lock". This is a distinctly difficult speech perception task for Japanese speakers as it is a non-native phonemic contrast. Hence, for clinical populations, depletion of learning resources makes many tasks highly challenging and reduces the threshold of "desirable difficulty" away from the sense in which this term has been applied in the non-clinical literature. Similarly, in non-clinical studies, it is the exceptionally demanding learning tasks where an errorless advantage is most prominent.

Another theme to emerge from the Jokel and Anderson and Noonan et al. studies is the application of errorless learning to discrete and specific clinical disorders under the umbrella of the dementias. The importance of this development is underlined by the contrasting results reported within these studies. Jokel and Anderson found an errorless advantage for six of seven of their participants with semantic dementia at an immediate post-intervention time-point and then one month later. However, by three months post-intervention, the errorless advantage had depleted to still significant accuracy levels, but ones similar in magnitude to the errorful methods. Noonan et al. purposefully replicated the errorless word learning method used previously in stroke aphasia studies (Conroy, Sage, & Lambon Ralph, 2009b; Fillingham, Sage, & Lambon Ralph, 2006) with people with anomia in the context of Alzheimer's disease and, in so doing, found similar results; no benefit of EL over EF methods. In this way, their study straddles both memory and language rehabilitative themes.

At first glance, these studies mirror the established findings linked to memory as opposed to language studies, i.e., an errorless advantage for memory studies, but equivalent learning using both errorless and errorful methods in language studies. Jokel et al. point out that their participant group of semantic dementia (SD) have spared explicit memory with pronounced deficit in semantic memory. This meant that explicit verbal learning was compromised because of its dependence on a depleted semantic network. It may be that the extent of explicit memory impairment was proportionate to the errorless learning benefit obtained, which, although significant at early time-points post-intervention, did not prove more durable relative to errorful methods in the longer term.

Noonan et al. explain that the profile of cognitive deficits in Alzheimer's disease (AD) consists of depletion in the ability to encode and retain explicit episodic memories with anomia, attentional and executive impairments alongside relative preservation of implicit memory together (Lambon Ralph, Patterson, Graham, Dawson, & Hodges, 2003). Despite the hypothesis that an errorless learning benefit would be evident against this background, this was not the case. Noonan et al. considered this outcome in relation to the classic experimental studies of learning in amnesia which utilised stem-completion and pair-associate learning of arbitrary word lists in which errors were induced, as opposed to picture naming in their study wherein errors arose in a more ecological fashion. Picture naming also has the distinction of recruiting residual object knowledge, potentially reducing error frequency.

The somewhat differing findings between the Jokel et al. and Noonan et al. studies and the theoretical rationale offered for these findings highlight the range of interacting variables which we need to begin to systematically control for in subsequent research in order to progress our understanding of the “who”, “when” and “why” of a rehabilitative benefit of errorless learning. These include error frequency and category, profile of participants’ cognitive impairments, and the demands of the learning task.

ERRORLESS LEARNING AND LANGUAGE REHABILITATION

The three studies that focus on primarily linguistic deficits secondary to neurological damage show evidence of innovative applications of errorless learning in rehabilitation. Raymer et al. compared an errorless verbal naming treatment against a gestural facilitation of naming treatment which incorporated both an errorless gesture and word production method, in participants with aphasia following stroke. Aside from the novel evaluation of a specifically errorless approach to gesture, this study is distinctive within the errorless learning literature for demonstrating indirect therapeutic gains. They show effects of treatment in functional communication skills beyond the primary outcome of treated and untreated items tested via picture naming. Importantly, these wider benefits derived from both the gestural method, which had the added benefit of training a compensatory skill for use in everyday communication, and the errorless method, across both phonologically and semantically impaired participants.

Raymer et al. included a barrier activity within both gestural and purely verbal errorless methods in which participants conveyed to the clinician the key word or gesture for a target word to which the clinician was blind. Importantly, they encouraged participants to engage only in informed guesswork (not to attempt gestures/verbal naming if they were unsure). In this way, their study harnessed the benefits of both an errorless production method in combination with a retrieval practice method, as advocated by Middleton and Schwartz, and specifically captured the benefits of “desirable difficulty” by ensuring this retrieval practice was successful. Further aphasia and dementia studies could benefit from ways to compare directly the broader functional communication outcome. Raymer et al.’s methods to support and measure generalisation of learning will be a useful example of how to start tackling this important issue.

Whiteside et al. evaluated a self-administered, computer-based error-reducing therapy approach to enhancing speech production in participants with apraxia of speech (AoS). Just as Middleton and Schwartz pointed out the tension between errorless learning and retrieval practice in terms of learning effects, the Whiteside et al. study highlights another important clinical tension which needs to be grappled with. In order to ensure sufficient training intensity (a known contributor to therapy outcome), this study opted for self-administration, which inevitably prevents precise information about the extent to which participant performance is errorless. The study adopted a painstakingly rigorous approach to ensuring that the lead-in to speech production is incremental, e.g., silent observation of target word production, to imagined production followed by immediate and then slightly delayed repetition. In this way, it becomes entirely plausible to argue that for participants who do show a therapy effect, this will have necessitated successfully reducing errorful behaviours in the training phase.

Whiteside et al. reflected on whether errorless learning specifically facilitates automatic, procedural learning. Whereas some linguistic skills may entail explicit knowledge (for example, the link between a word form and its referent in naming), other skills appear implicit, particularly fluent speech production. These authors, therefore, contend that speech production represents a motor skill of which we have little conscious knowledge or control and thus more closely represents unconscious procedural memory. The hypothesis that EL methods are more appropriate to implicit mechanisms such as speech production in AoS, and EF methods are better suited to explicit knowledge of semantic-phonological links in naming could be interrogated by designing a large case-series of aphasic participants who display the continua of symptoms associated with AoS at one end with more anomic/semantic-phonological processing impairments at the other end.

Finally, Conroy and Scowcroft justify the novel method within their study with reference to the ease and efficiency with which participants with aphasia post-stroke engage in errorless methods (Conroy et al., 2009a, 2009b; Fillingham, Sage, & Lambon Ralph, 2005a, 2005b). The logic of this method is that, if decreasing cues provide an easy, time-efficient and progressively challenging method through which to train word retrieval, then one benefit may be expanding lists of word targets. Although the type of indirect communication measures taken by Raymer et al. were not collated in this study, Conroy and Scowcroft assumed that targeting more, rather than fewer, vocabulary items is more likely to enhance everyday communication skills. Also, the inclusion of independent home practice may appear counter-intuitive in an errorless study but, as in Whiteside et al., the risk of loss of control over error production could arguably be outweighed by the learning reinforcement benefit of independent training.

Conroy and Scowcroft conclude their discussion by linking their findings from participants with aphasia to previous work within memory rehabilitation which has sought to gauge some sense of the limits of these methods in terms of the potential of rehabilitation (Jansari, McGibbon, Haslam, & Anderson, 2009). As well as considering the limits of learning with reference to the risk of "system overload" or "catastrophic interference" (Ellis & Lambon

Ralph, 2000; Snell, Sage, & Lambon Ralph, 2010), rehabilitation research within stroke and degenerative neurological disease should be mindful of the critical need to build maintenance training into therapeutic programmes to ensure gains are as robust as possible over time. In their different ways, the Conroy and Scowcroft homework target-list training and the Whiteside et al. independent software-based practice both provide examples of how this might be implemented.

In summary, this overview highlights several ways forward for future research. These include specifying both the frequency and nature (e.g., induced versus spontaneous) of error production in errorless learning studies, such that a critical degree of errorlessness which may confer benefit can be established. Furthermore, different patterns of error production need to be systematically evaluated with regard to their interaction with a range of participant clinical profiles and the demands of the specific learning tasks (e.g., picture learning versus stem-completion versus pair-associate learning, etc.). Testable hypotheses which can be directly investigated have emerged, in particular, the suggestion that EL methods may be more appropriate to implicit mechanisms such as speech production in apraxia of speech/AoS, and EF methods better suited to explicit knowledge of semantic–phonological links in aphasic naming. More generally, aphasia and dementia relearning studies should be mindful of the critical need to build maintenance training into therapeutic programmes to ensure treatment gains are as robust as possible over time. Studies can ensure a greater impact in terms of health outcomes if they incorporate some measures of broader functional change brought about by the direct learning outcomes.

CONCLUSION

The UK Medical Research Council has provided a framework for designing and evaluating complex interventions to improve health (Campbell et al., 2000). This depicts a continuum of increasing evidence for health interventions from preclinical theoretical modelling through to exploratory, and then randomised controlled trials. Considering the evidence for errorless learning as a treatment for memory and language impairments within neurological rehabilitation as represented within this special issue, huge progress is apparent at the levels of modelling work, feasibility and practical implementation. There is a clear need for further modelling work together with studies which seek to establish optimal parameter-setting as to critical variables relating to profiles of cognitive impairments, the range of training tasks, and frequency of error production, which lead to an errorless learning benefit.

The demographic pressures of ageing populations within which neurological disease will inevitably increase point to an urgency in the need to advance rehabilitation science and implementation (World Health Organization, 2006). Within this, there will be a role for integrating optimally targeted and efficient relearning therapies together with pharmacological treatments and more general forms of cognitive stimulation, perhaps via technology (Robertson, 2011). Considering the significance of error production within relearning therapies across the cognitive domains of language and memory and across a range of key neurological conditions represents a useful contribution to this process.

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