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Using online cognitive tasks to predict mathematics low school achievement

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ABSTRACT

This study aimed to analyze the validity of an online cognitive screening battery to predict mathematic school achievement using artificial neural networks (ANNs). The tasks were designed to measure; selective attention, visuo-spatial working memory, mental rotation, and arithmetic ability in an online, game-like format. In the first study, we investigated the cognitive performance of students with low and typical achievement in mathematics and language. In the second study, we developed an ANN to classify mathematics school achievement. Finally, we tested the adequacy of this network to classify an unknown sample to the ANN. Most of the performance differences in the battery were related to mathematics achievement. The ANN was able to predict mathematics achievement with acceptable accuracy and presented equivalent results in a simulation involving a different sample. We suggest that this assessment model combining ANNs and online cognitive tasks may be a valuable tool to research low school achievement in school settings.

1. Introduction

Low school achievement has been investigated with a variety of approaches. Some of the studies in this field have provided evidence to explain neuropsychological differences related to low school achievement (Bull, Espy, & Wiebe, 2008; De Smedt et al., 2009; Gathercole, Alloway, Willis, & Adams, 2006; McLean & Hitch, 1999). Substantial research has investigated the neuropsychological correlates of mathematical reasoning (Berg, 2008; Imbo, Duverne, & Lemaire, 2007; Passolunghi & Siegel, 2001; Rasmussen & Bisanz, 2005; Ward, Sagiv, & Butterworth, 2009; Wu et al., 2008) and language learning (Gathercole et al., 2006; Rucklidge & Tannock, 2002; Watkins & Glutting, 2000). In these neuropsychological studies, certain cognitive skills such as: working memory, attention and arithmetic are associated with low achievement in different school subjects (Gaddes & Edgell, 1994). The knowledge of the association between these cognitive functions and their respective brain substrates has furthered our understanding of the mechanisms behind specific learning difficulties, which is crucial for the development of adequate interventions for low achievement in school.

In formal education settings, the neuropsychological assessment usually takes place when an individual is struggling in school and a learning disability is suspected (Silver et al., 2008). However, this process may represent years of low achievement and frustration that can affect the student's self-efficacy toward his or her performance. Considering this problem, it is relevant to develop a cognitive screening method that can assist in the early detection of learning disabilities.

Some cognitive assessment batteries have been investigated in the attempt to predict low achievement (Glutting, Watkins, Konold, & McDermott, 2006; Glutting, Youngstrom, Ward, Ward, & Hale, 1997; Watkins & Glutting, 2000). Nevertheless, the majority of these neuropsychological assessment batteries require a specialized professional for administration, scoring and interpretation of the results (Maruta, Guerreiro, de Mendonca, Hort, & Scheltens, 2010). This can be one of the main difficulties faced when administrating such instruments with the purpose of large scale screening for cognitive difficulties in school settings. The importance of early identification of learning disabilities has stimulated other approaches, such as the use of risk analysis. to anticipate and prevent the problem (McDermott, Goldberg, Watkins, Stanley, & Glutting, 2006). However, the authors of this study verified a bias toward low achievement identification of ethnic minority

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and disadvantaged students. Furthermore, the risk analyzed by this study did not take into account specific cognitive skills that might be related to more specific learning disabilities.

Considering the need for early identification of learning disabilities based on cognitive skills measurement, it would be advantageous to develop an instrument that allows a fast, self-administered, cognitive screening of a large number of students with acceptable psychometric qualities and predictive capabilities. However, self-administration may be a problem, since some studies have suggested that lack of motivation affects participant effort during the tasks (Bauer, O'Bryant, Lynch, McCaffrey, & Fisher, 2007; Courtney, Dinkins, Allen, & Kuroski, 2003). For this reason, self-administered instruments should be interesting enough to motivate children and adolescents to undertake it.

Results from a recent study (McPherson & Burns, 2008) suggest that scores in computer games (space code and space matrix) designed for psychometric purposes are better predictors of school achievement than traditional tests (Digit Symbol, Visual Matching, Decision speed, Picture Swaps, Dot matrix and the Raven's Standard Progressive Matrices). The authors suggested that motivation affects cognitive performance on traditional tests and this effect is reduced in computer games, since they provide a motivating environment.

A cognitive screening battery in game format could be useful for investigating school achievement of a large sample in a self-administered fashion. Therefore, this study aims to investigate the validity of a set of computer games to measure four cognitive skills and to predict students' school achievement in the modules of mathematics and language (Portuguese). The battery aims to assess four cognitive skills: selective attention, visuo-spatial working memory, mental rotation and arithmetic. These skills, excluding selective attention, are specifically associated with mathematical achievement (Berg, 2008; Bull et al., 2008; De Smedt et al., 2009; Geary, Hoard, Byrd-Craven, Nugent, & Numtee, 2007; Wu et al., 2008). Consequently, it is hypothesized that cognitive performance on this battery will be more related to mathematics achievement than to language.

Furthermore, it is conjectured that the performance variables of this battery can be used as predictors of mathematics school achievement, since all tasks (not including selective attention) are related to mathematics achievement. In order to scrutinize this possibility, the second part of this study is dedicated to the design, test and implementation of a pattern recognition artificial neural network (ANN) which uses participant performance on the battery to predict achievement in mathematics. Considering that one of the motivations for making use of the aforementioned cognitive screening tool is to identify low achievement risk students in a broad educational context, the development of such an ANN can be regarded as a relevant field application. Importantly, the combination of online cognitive tasks in a game format with ANN is an innovative way of dealing with low achievement in education, demonstrating a further role for computers and technology in improving education.

The capacity of nonlinear classification, which allows identification of complex relationships between variables, is one of the major advantages of ANNs (Buscema, 2000; Sargent, 2001; Starzomska, 2003). For example, a student could present low achievement in mathematics because of a lack of attention in general, low visuo-spatial working memory, or both. Furthermore, it has been demonstrated that individuals with high working memory capacity are those who show the largest performance decreases on highly demanding mathematical problems under pressure (Beilock & Carr, 2005). This means that the relationship between cognitive performance and low achievement is not necessarily linear. Therefore, in order to build a robust system for early low achievement detection, a nonlinear classifier may be needed.

The main drawback of the ANNs is the lack of interpretability of the model outputs (Sargent, 2001). Taking this limitation into account, this study examines the differences in cognitive performance related to mathematics and language achievement using traditional statistical techniques before developing the ANNs classifier. Therefore, the objective of this study is to develop and test an ANN able to predict mathematics low achievement based on the students' performance in a set of online cognitive tasks in a game-like format. In order to achieve that, we first analyzed the differences in the cognitive performance among students with typical or low achievement in mathematics and language. Second, we developed, trained, and tested an ANN to predict mathematics low achievement based on several performance measures in a set of online cognitive tasks. Third, we tested the network's capability of correctly classifying typical and low achievement using data from other students six months later in order to examine whether this ANN is able to generalize the results to samples which were not previously known.

We emphasize that these results are preliminary in a sense that we are not testing a final product for school achievement prediction. Rather, we intend to describe and demonstrate a new applied idea in the learning field that can be used and tested with other online tasks developed elsewhere.

2. Method

Considering the research objectives, it was necessary to divide this study into three main sections: 1) analysis of the differences in cognitive performance related to mathematics and language achievement; 2) development, training and evaluation of an ANN to predict low achievement in mathematics; and 3) field test and validation of the neural network to predict low achievement in new participants (not included previously) selected using slightly different criteria. The research design and the main layout of the cognitive tasks are described in Fig.1.

2.1. Participants in studies 1 and 2

The participants were recruited from a private school in Brazil. From 860 students assessed, the bottom 5 school grades and 5 typical grades (controls) for both Language (Portuguese) and Mathematics from each class within the school were selected. Participants without complete data were excluded from data analysis, leaving 348 students in total. From this sample, 51 participants presented low achievement in both language and mathematics, others only in mathematics ($n = 80$) or language ($n = 54$), and the remaining students did not show any difficulties in either of these modules ($n = 163$). The age range among the participants varied from 9 to 18 years (mean = 13.2, standard deviation = 2.04). The number of students in each age group was similar (9–10, 11–12, 13–15, and 16–18 years). They were also evenly distributed in relation to gender, with 177 females (50.9%) and 171 males (49.1%).

2.2. Participants study 3

The participants in this study belong to the same school as those in the previous studies. From each school class, 6 students were selected, 3 of them with grades above the minimum grade for approval (7.0) and three with grades below it in mathematics. It is important to note