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“Cerebellar Challenge” for Adolescents at Risk of School Failure: Evaluation of a School-Based “Whole Person” Intervention

Panagiota Blouchou¹ and Roderick I. Nicolson^{2*}

¹ Department of Psychology, University of Sheffield, Sheffield, United Kingdom, ² Department of Psychology, Edge Hill University, Ormskirk, United Kingdom

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Waganesh A. Zeleke,
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University of Dundee, United Kingdom

*Correspondence:

Roderick I. Nicolson
rod.nicolson@edgehill.ac.uk

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Forty adolescents at risk of school failure, including 18 with a diagnosis of dyslexia, were assessed on measures of physical, cognitive and affective well-being. Overall both groups of participants showed marked signs of anxiety together with at risk performance on a range of cognitive and physical measures, with the dyslexic participants significantly more adversely affected on almost all measures. Half of the participants then undertook an 8 weeks internet-based “cerebellar challenge” programme within their school environment, with the remainder having equivalent time in the existing “School Support as Usual” (SSAU) activities. Compared with their initial performance, and with the SSAU group, the intervention group showed significant improvement on measures of motor performance, declarative learning, procedural learning, and mental health, both for those with dyslexia and those without. The findings are interpreted in terms of increased self-efficacy and improvements in cerebellar and hippocampal function. Given its scalability, the intervention may prove valuable for many adolescents at risk of school failure.

Keywords: declarative memory, cerebellum, hippocampus, dyslexia, special educational needs, balance, anxiety, Zing

INTRODUCTION

It is acknowledged internationally that the current generation of adolescents is of vital importance for future societal needs (Patton et al., 2018). However, there is increasing concern regarding the three major dimensions of human well-being—physical well-being, affective well-being and cognitive well-being—of current adolescents. Recent surveys indicate that physical activity declines in adolescence (Farooq et al., 2018), with a WHO survey of 1.6 million adolescents in 48 countries concluding that 81% undertook insufficient physical activity (Guthold et al., 2020). Around one in five of British or US adolescents suffer from significant mental health issues (Merikangas et al., 2010; Government Statistical Service, 2018), with a higher recent estimate of nearly 40% in deprived areas of the UK (Deighton et al., 2019). The PISA international survey of reading (OECD, 2019) estimates that nearly 20% of UK and US 15 year olds have not reached level 2 (able to identify the main idea in a piece of text of moderate length) reading ability.

Cognitive well-being refers to the function of the “central executive” (Baddeley and Hitch, 1974), the brain functions regulating the brain’s information processing requirements, including working memory, memory retrieval, speed of processing, task switching and maintenance of attention. Recent developments (Prencipe et al., 2011; Diamond, 2013) highlight the importance of “hot”

executive function, including control of impulsiveness, anger and risk taking. There is emerging evidence of the intrinsic interconnectedness of these functional dimensions, with theoretical developments in terms of embodied cognition (Barsalou, 2008) and embodied emotion (Niedenthal et al., 2005; Niedenthal, 2007; Koole, 2009) highlighting the interdependence of cognitive, physical and emotional well-being. Neuroscience approaches highlight the importance of brain circuits combining specialist processing capabilities (Buckner et al., 2011; Yeo et al., 2011; Koziol et al., 2012).

Educationally there is growing evidence of this interdependence, with exercise benefitting physical and mental well-being (Cotman et al., 2007; Hillman et al., 2008; Chen et al., 2017), stress adversely affecting all three (McEwen, 2012, 2013; Dupere et al., 2015; Schwabe, 2017; Engert et al., 2019; Joos et al., 2019); and the “growth mindset” intervention having beneficial effects on resilience to social stress (Yeager et al., 2016).

Around 20% of adolescents drop out of school in the UK and USA (OECD, 2020), with consequent disadvantage in terms of poverty, employment and morbidity compared with those who complete secondary education (Clark and Royer, 2013; WHO, 2013; Autor, 2014; Kaplan et al., 2017; Goldman et al., 2018; Psacharopoulos and Patrinos, 2018). Of particular interest for this study, there is further interaction between poor mental health and poor academic performance in adolescents dropping out of school (Esch et al., 2014; Butterworth and Leach, 2018). A recent analysis (Dupere et al., 2018, p. 205) concluded “*These findings suggest that to improve disadvantaged youths’ educational outcomes, investments in comprehensive mental health services are needed in schools struggling with high dropout rates, the very places where adolescents with unmet mental health needs tend to concentrate.*”

An alternative, and complementary, approach may be derived from the psychological concept of “engagement,” and an influential prospective study (Finn and Rock, 1997) established that school engagement was strongly linked to “academic resilience” (completing schooling) in adolescents at risk of dropping out. A subsequent influential study (Skinner et al., 2008) concluded that behavioral engagement and student autonomy might play a more direct role than emotional engagement (or disaffection). Subsequent work (Jang et al., 2010; Reeve, 2012) included self-determination theory (Deci and Ryan, 1985; Ryan and Deci, 2017) as the key theoretical underpinning. A further development (Cheon et al., 2019) highlights three “autonomy” factors, namely “autonomy satisfaction,” “autonomy frustration” and “autonomy dissatisfaction,” with the latter leading to a passive, disengaged attitude. The authors conclude that autonomy-supporting teaching diminishes the risk of autonomy dissatisfaction, thereby leading to greater student engagement.

A related, though independent, approach of attested general utility for adolescents with learning difficulties, derives from the growth mindset framework (Dweck and Leggett, 1988) in which children are encouraged “*to see intellectual abilities not as fixed but as capable of growth in response to dedicated effort, trying new strategies and seeking help when appropriate*” (Yeager et al., 2019). The “National Study of Learning Mindsets” involved

12,500 children from 134 US schools and concluded that “*A short (less than one hour), online growth mindset intervention ... improved grades among lower-achieving students*” (Yeager et al., 2019). These are extraordinary results, indicating the power of positive interventions to overcome a history of stress and shame. Furthermore, given that the brain is indeed changing significantly around puberty, adolescence does provide a major opportunity for new learning and neural change.

One major cause of anxiety and depression is stress, and there is strong survey evidence of high stress levels in schools. A US study revealed that 27% of 1019 teenagers reported experiencing a level of stress that was an 8, 9, or 10 on a 10-point scale during the school year (American Psychological Association, 2014) and over 70% of 920 13–17 respondents rated anxiety and depression as a major problem among their peers (Pew Research Center, 2019). The impact of heightened stress on behavior is potentially highly significant, with studies revealing impaired ability for “declarative” information processing (Schwabe and Wolf, 2013; Wirkner et al., 2019), and decision making processes that are more risk taking, more reward seeking and more disadvantageous under conditions of uncertainty (Starcke and Brand, 2016). Depression also leads to task-specific impairments in information processing (Gotlib and Joormann, 2010; Hubbard et al., 2016; Lau and Waters, 2017; Schweizer et al., 2019), with a recent proposal that common mechanisms may be involved for the “internalizing disorders” of depression and anxiety (Hankin et al., 2016).

It is important to note that a significant proportion of adolescents at risk of school dropout will have Special Educational Needs, and that there is longstanding evidence that dyslexic children may suffer from heightened levels of stress, anxiety and depression (Duane, 1991; Boetsch et al., 1996). Indeed, in his seminal article on the vicious circle he termed the Matthew Effect, Stanovich (1986) observed “*Initial and specific difficulties in learning to read may result in generalized deficits in learning because of the behavioral-cognitive-motivational spinoffs from failure at such crucial tasks as learning to read*” (p. 389). Unfortunately, despite early work (Geisthardt and Munsch, 1996; Alexander-Passe, 2006; Burden, 2008) there has been no systematic analysis of mental health issues in dyslexic children, though recent studies and reviews indicate that dyslexic adolescents do suffer from internalizing problems (anxiety and depression) but not necessarily lower self esteem (Boyes et al., 2018, 2020; Eyre et al., 2019; Gibby-Leversuch et al., 2020).

This introduction has outlined a range of potential contributors to school dropout, highlighting the interplay between the three axes of mental health, physical health and academic health. It has also noted the value of increasing perceived autonomy and of creating a “growth mindset” in interventions designed to alleviate mental health and self esteem issues. We turn now to a different type of intervention, one based on theoretical analyses of neuroplasticity and how it may be enhanced.

There is strong evidence that natural activities, such as exercise, can improve not only physical fitness but also cognitive fitness, and even stimulate the growth of new brain neurons and connections (Hillman et al., 2008; Hoetting and Roeder, 2013).

There is also strong evidence (Niemann et al., 2014) that exercise can potentiate the brain for new learning, with “coordinative balance” exercises, such as balance training or tai-chi, leading to neural growth in the hippocampus—a core structure for explicit learning and memory—and also in the cerebellar-cortical loop (Burciu et al., 2013; Ben-Soussan et al., 2015)—a core network for implicit learning and coordination.

The above considerations informed the design of the current study. We wished to evaluate the effectiveness of a novel internet-based “cerebellar challenge” intervention, the Zing intervention (www.zingperformance.com). This intervention was originally developed to tune up the coordination abilities of top sporting performers, using a series of graded exercises designed specifically to improve three performance dimensions: sensorimotor coordination, eye movement control, and dual tasking. However, extensive feedback had suggested that the programme was valuable for many average performers. Consequently the system was embedded in an internet-based “game” format designed to challenge and stimulate the user to keep improving their performance. Zing Performance offer a number of courses specifically tailored to each individual user, with applications in sporting areas, organizational development, in education.

The Zing system involves a series of graded activities on three dimensions—dynamic activity (patterned movement sequences), focus activity (developing the ability both to concentrate and to “dual task”), and stability activity (coordinative balance). Underpinning the approach is the technique of vestibular stimulation. Rather than cardiovascular exercise, which is designed to have energetic use of highly practiced routines, or even coordinative balance such as tai-chi, which does involve learning new actions, vestibular activities are designed to cause abnormal input for the vestibular system, for example by requiring the user to put their head on one side while undertaking tasks. This presents the vestibular system, and the cerebellum, with an immediate challenge, requiring activation of many circuits to cope with the ensuing proprioceptive feedback.

A typical course lasts 6 months and is composed of daily physical activities and digital video games. An example of a low level focus activity (at the time of the study) is given in **Figure 1**. A video is also available for each activity.

Recent research with older adults (Gallant and Nicolson, 2017) examining the effectiveness of the Zing intervention over a 10 weeks period revealed high effectiveness with significantly greater improvement than a “no treatment” control group on measures of balance, coordination and declarative memory.

The Zing intervention has a “staircase” approach to systematically building difficulty on each of the dynamic, focus and stability activity dimensions. The initial positioning on the three staircases is designed to reflect the user’s initial performance, and the rate of progression is then determined by the user’s self-assessment of their performance on the current session. A major component of the Zing introductory material is a series of videos highlighting the plasticity of the brain and the importance of deliberate practice and exercise in creating positive changes, and the broader benefits of neuroplasticity in improving performance even in everyday situations, not only for

physical coordination but also mental coordination in terms of working memory and attentional function. Extensive feedback of progress against goals is provided monthly. Consequently, it effectively fulfills the criteria of user autonomy, user engagement, and growth mindset.

MATERIALS AND METHODS

Ethical Permission was granted by the Department of Psychology, University of Sheffield ethics committee (ref 007270).

Participants

The study was conducted in collaboration with “Sheffield Futures,” a UK government-funded initiative tasked with improving retention of adolescents at risk of dropping out from school. Sheffield Futures assisted with the recruitment of participants and access to the school. A sample of 40 students aged 14 and 15 years, from Year 10, participated by invitation of the Learning Provider. Participants were randomly assigned by the learning provider to the Zing intervention group or the control group (School Support As Usual); 20 students (11 male, 9 female) were assigned to the intervention group and 20 students (10 male, 10 female) to the control group. Eighteen students with dyslexia (9 in intervention group), and 22 students without dyslexia (11 in intervention group) participated in the study. The mean age overall was 14.7 years, with mean ages for the intervention group being 14.8 and 14.6 years (dyslexic and non-dyslexic) whereas corresponding means for the SSAU group were 14.7 and 14.9, respectively. None of the students with dyslexia were known to have other developmental or neurological disorders (e.g., ADHD, Specific Language Impairment, autistic spectrum disorder). The students who were identified as having dyslexia had a formal/suspected diagnosis of dyslexia either from the educational psychologist within the school or from a Diagnostic Center outside the school, whereas for the non-dyslexic group, students were required to have no previous history or diagnosis of learning or other developmental difficulties.

Materials and Apparatus

We wished to evaluate changes in all the core physical, cognitive and affective domains, using simple but normed tasks where possible. Nine of the tasks in the study were derived from the Dyslexia Screening Test (DST-S) (Fawcett and Nicolson, 2004), test battery from which were included Rapid Naming, 1 min Reading, 2 min Spelling, Digit Span, Bead Threading, Postural Stability, 1 min Writing, Semantic Fluency and Verbal Fluency tasks. The DST-S was designed to assess secondary school students between 11.6 and 16.5 years of age, and to distinguish students who are at risk of reading failure (Fawcett and Nicolson, 2004). It is a 30 min test designed to provide a “profile” of performance on literacy, executive function, physical coordination and balance, and has been used for research purposes demonstrating that it is a valid tool for assessing students (Fawcett et al., 2001; Reynolds et al., 2003; Reynolds and Nicolson, 2007). The DST-S test reports a test-retest reliability of 0.76 (Fawcett and Nicolson, 2004).

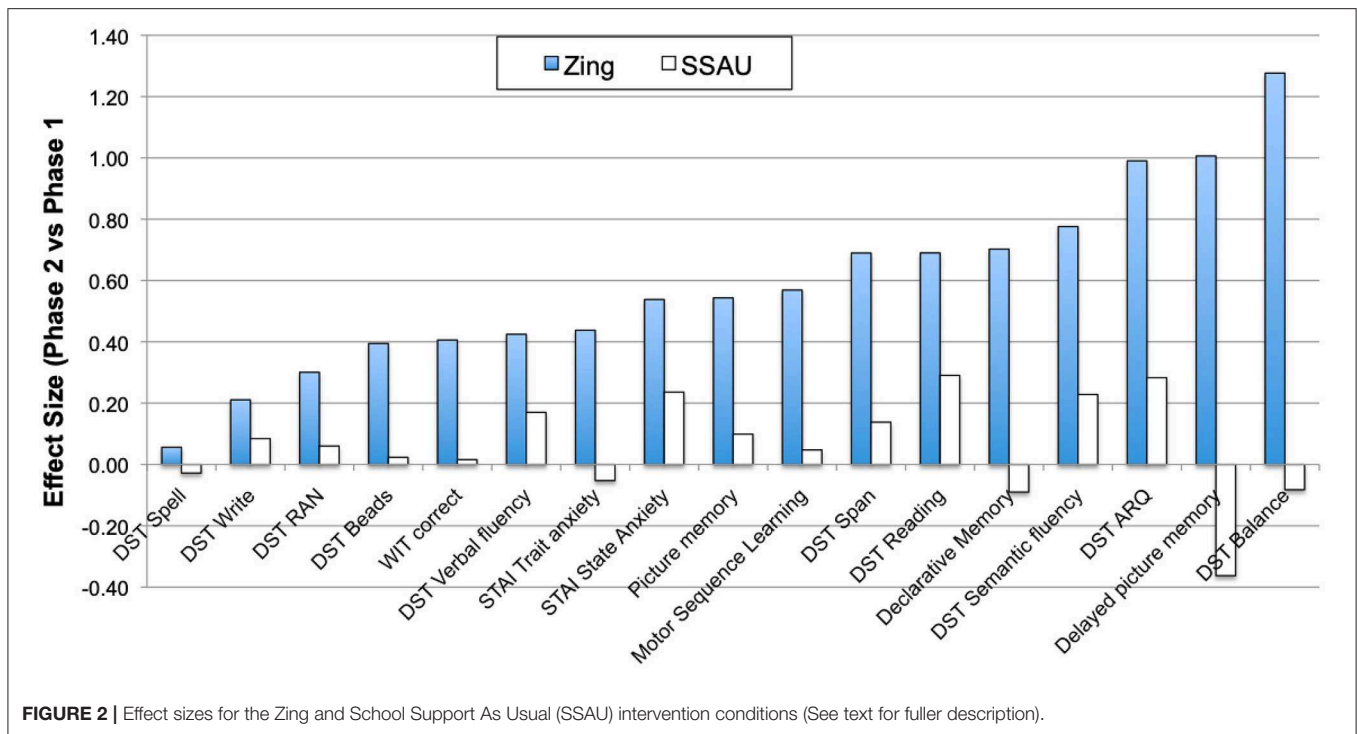


FIGURE 1 | Illustration of a Zing Performance low level focus activity.

Four additional tasks were administered in the study, derived from the Learning Assessment Battery (LAB) (Nicolson, 2010) and the South Yorkshire Ageing Study (SYAS) (Tarmey, 2012) to assess procedural and declarative memory. The SYAS Declarative Memory test probes recall for the details of a sheet of 14 simple clip art pictures presented for 30 s (for example, what color were the clown's shoes?) The SYAS Picture Recall test assesses recall for a set of 20 pictures of common objects, presented sequentially for 1 s, including both immediate recall and delayed recall after 20 min. Procedural Learning was assessed using the LAB Motor Sequence Learning task. This is modeled on Korman et al. (2003) and participants have to learn and repeat a sequence of four finger presses, by resting the four fingers of their preferred hand on the keyboard keys FTUK and then produce a given sequence (e.g., FKUT FKUT FKUT...) 18 times. Two such sequences are used, and the score returned is the number correct on the second sequence, to minimize unfamiliarity effects. The LAB Word Identification Task was also used to assess the display time needed to read a word by presenting the stimulus for shorter and shorter periods. These tests were selected on the basis that there are no other established tests of procedural and declarative learning, and, together with DST-S tests, proved effective in detecting performance changes in a study with Zing in older adults (Gallant and Nicolson, 2017).

Finally, for the Affect suite, the State Anxiety Inventory (SAI) (Spielberger et al., 1970) was used to assess the current state of anxiety, together with the Trait Anxiety Inventory to assess dispositional anxiety. The State-Trait Anxiety inventory is a well-established measure assessing current state of anxiety (State) and dispositional anxiety (Trait) and it has previously been used with adolescent samples (Cameron et al., 2007). In the State and Trait Anxiety Inventory, internal consistency coefficients have ranged from 0.83 to 0.94 for the State scale, and from 0.86 to 0.91 for the Trait scale for high school students and adolescents (Gaudry et al., 1975; Spielberger, 1983). Test-retest reliability coefficients have ranged from 0.31 to 0.86 over a 2 month interval (Spielberger, 1983).

This basket of tasks was chosen to allow “whole person” measures to be derived, including not only measures of literacy attainment, but also the underlying executive capacity in terms of mental coordination, declarative learning, physical coordination, procedural learning and affect. In the analyses, six key tasks were used as “probes” for these capabilities, namely Declarative Memory as a probe for the ability to extract and remember detail from a complex presentation; Delayed Picture Recall as a probe for the ability to recall information over a 20 min period of interfering activities; Motor Sequence Learning as an index of physical procedural learning; Postural



Stability as an index of proprioceptive learning (ability to adjust to an unexpected stimulus disturbing balance); and Trait Anxiety as an enduring index of affect. A sixth measure, the composite DST-S At Risk Quotient gives an index of risk of dyslexia.

Procedure

Permission to conduct the study was granted by the school officials. Parents and students were notified and provided with an explanation of the study, and parents had to give their permission and sign the consent forms in order for their child to participate in the study. Prior to the data collection, the parent consent forms along with the students' assent were obtained by the Researcher.

The study was designed as a repeated measures pretest—intervention—posttest format. Participants were asked to complete the battery of tasks before taking part in the 8 weeks Zing intervention, and then asked to repeat the same battery of tasks 1 or 2 weeks after completing the intervention. The full Zing 360 session programme is designed for at least 6 months, with two sessions per day. However, for the practicalities of the current study, the intervention was designed for 8 weeks, so that it suited the school schedule. Consequently, this study was very much shorter than recommended by the Zing designers. The period was, however, comparable to the 10 weeks intervention with older adults reported in Gallant and Nicolson (2017), a period that proved sufficient to establish marked changes in several measures with sufficient effect sizes to yield significant between-group differences if similar effects were obtained with the adolescent participants.

For both pre-test and post-test the assessment was completed in one session and lasted approximately for an hour. The participants were escorted to the classroom by the Learning Provider, who was outside the classroom during the assessment, but in close proximity, in case the children felt uncomfortable, for any reason. None of the participants asked for the Learning Provider to enter the classroom during the assessment. The participants completed the tasks in the following order: they first completed the State and Trait anxiety Inventory, in order to assess present levels of anxiety prior to completing the tasks, they then completed the remaining tests, with the Picture Recall test presented early, so that the interval before Delayed Picture Recall was filled with other tests.

Following the pre-test, participants were allocated randomly either to the intervention group or a "School Support As Usual" (SSAU) group. Intervention participants were required to undertake a minimum of 8 weeks vestibular stimulation provided by Zing Performance Ltd. The intervention took place in a computer room in the school, three times a week, for 40 min *per session*. The Researcher was present in the computer room in all the sessions to answer any questions and supervise the students while doing the exercises. The Learning Provider was also present in most of the sessions.

Initially, participants had to undertake an assessment to determine their strengths and weaknesses. After this, a 4 weeks programme was set for each participant individually, specifically designed to target their biggest needs. Each week, three exercises were assigned, with two of the three appearing at each session.

TABLE 1 | Descriptive statistics for the initial test battery (See text for further information).

Test	Non-dyslexic Mean (SD)	Dyslexic Mean (SD)	Effect size
RAN	3.77 (1.54)	1.67 (0.91)	1.36
Bead threading	3.82 (2.11)	2.06 (1.83)	0.83
One minute reading	3.50 (1.44)	2.28 (0.96)	0.85
Postural stability	3.73 (1.24)	2.67 (0.91)	0.85
Two minute spelling	3.95 (1.91)	2.22 (1.00)	0.90
Backwards digit span	3.36 (1.53)	1.94 (0.87)	0.93
One minute writing	3.14 (1.17)	2.11 (0.96)	0.88
Verbal fluency	3.50 (1.60)	2.17 (1.72)	0.83
Semantic fluency	3.36 (1.26)	2.72 (0.75)	0.51
ARQ	0.76 (0.29)	1.67 (0.37)	3.17
Declarative memory	13.18 (2.67)	11.00 (2.47)	0.82
Immediate picture recall	10.45 (1.71)	9.06 (2.16)	0.81
Delayed picture recall	10.00 (2.64)	8.06 (3.21)	0.74
Motor sequence learning	14.05 (1.65)	11.94 (2.07)	1.28
WIT speed	3.00 (0.45)	3.42 (0.49)	0.94
State anxiety	38.73 (4.41)	43.22 (5.34)	1.02
Trait anxiety	39.82 (5.13)	44.44 (5.46)	0.90

After 4 weeks, participants were reassessed before continuing onto unit two for the final 4 weeks.

RESULTS

The DST-S has age-based norms for each sub-test, and therefore the norms were used to convert raw scores into decile scores (1–10), with a decile score of 1 indicating the lowest 10% on the norms. The DST-S provides a method for deriving an overall “At Risk Quotient” which calculates the weighted mean of the at risk scores on the individual tasks. For simplicity, in calculations here a decile score of 1 was scored as 3, a decile of 2 scored as 2, and a decile of 3 scored as 1, with the remainder scored as 0, and the mean of these individual risk scores calculated as the Risk Quotient (ARQ). The SAI has clinically relevant cutoffs, which were used where appropriate, and the raw scores were used for the other tasks.

Two sets of analyses will be presented. First an analysis of the pre-test scores, with the primary concern being whether performance of the dyslexic group differed significantly from that of the non-dyslexic group. Second, the differential effect of the intervention will be investigated, with Phase (pre-test and post-test) being the repeated measures independent variable, and Condition (Zing vs. SSAU) and Group (Dyslexic vs. non-dyslexic) being the independent group variables.

Analyses of Initial Performance

Means and (standard deviations) for the battery of tasks for the pre-test are presented in Table 1. Effect size has been calculated following Cohen’s *d* formula (Cohen, 1988) as the difference between the mean of the two groups divided by the standard deviation of the non-dyslexic group. A positive effect size indicates that the non-dyslexic group have a better

score (higher performance, less anxiety) than the dyslexic group. Cohen suggested that an effect size of 0.2–0.5, 0.5–0.8, and 0.8 or greater be classified as small, medium or large respectively.

In terms of between-group inferential tests, all tasks except for semantic fluency revealed significant differences (uncorrected for multiple comparisons). The probability of 15 out of 16 tasks being significant in the predicted direction is vanishingly small, but even taking a conservative criterion of $p < 0.01$, all DST-S tasks except the two fluency tasks remained significant. By contrast only the WIT speed test of the non-DST cognitive tasks met the $p < 0.01$ criterion. The composite ARQ score was—as expected given the purpose of the DST-S—a particularly good discriminator between groups, accounting for 67% of the variance. Interestingly, the RAN sub-test was the best discriminator of the individual tasks (with dyslexia accounting for 41% of its variance).

Of particular interest in this analysis are the two anxiety measures, and in fact both were significant at the $p < 0.01$ level, with dyslexia accounting for 18 and 17% of the state and trait anxiety scores, respectively. According to the State Anxiety Inventory manual, the majority (66.7%) of students in the dyslexic group fell into the “high anxiety” category (scores > 40). In contrast, less than half of students (40%) in the non-dyslexic group showed high levels of state anxiety. For the Trait Anxiety measure, 72.2 % of the dyslexic group showed “high anxiety category” (scores > 40), compared with 54.5% for the non-dyslexic group.

Compliance and Attitudinal Findings

The participants evaluated the intervention as very helpful and easy to implement, both in terms of accessing the online platform and in terms of difficulty of the exercises. Most of the students said that they enjoyed the exercises and that they helped them

TABLE 2 | Pre-intervention and post-intervention means and standard deviations for the task battery for the Intervention group and the School Support as Usual (SSAU) group.

	Measure	Condition	Pre-intervention Mean (SD)	Post-intervention Mean (SD)	
Literacy	One-min reading	Intervention	2.95 (1.31)	3.90 (1.29)	
		SSAU	2.95 (1.46)	3.35 (1.49)	
	Two-min spelling	Intervention	3.55 (2.04)	3.65 (1.49)	
		SSAU	2.80 (1.43)	2.75 (1.41)	
	One-min writing	Intervention	2.65 (0.93)	2.90 (1.02)	
		SSAU	2.70 (1.41)	2.80 (1.05)	
Physical coordination	Bead threading	Intervention	2.95 (2.35)	3.80 (1.67)	
		SSAU	3.10 (2.12)	3.15 (1.38)	
	Postural stability	Intervention	3.05 (1.27)	4.60 (1.04)	
		SSAU	3.45 (1.14)	3.35 (1.42)	
	Fluency	Rapid automatized naming	Intervention	3.10 (1.65)	3.60 (1.46)
			SSAU	2.55 (1.67)	2.65 (1.98)
Verbal fluency		Intervention	2.40 (1.60)	3.15 (0.99)	
		SSAU	3.40 (1.81)	3.70 (1.38)	
Semantic fluency		Intervention	3.05 (0.99)	3.90 (0.97)	
		SSAU	3.10 (1.12)	3.35 (0.99)	
Memory	Backwards digit span	Intervention	3.05 (1.35)	4.05 (1.27)	
		SSAU	2.40 (1.50)	2.60 (0.82)	
	Immediate picture recall	Intervention	9.45 (2.19)	10.55 (2.16)	
		SSAU	10.20 (1.82)	10.40 (1.72)	
	Delayed picture recall	Intervention	7.65 (2.06)	10.70 (2.39)	
		SSAU	10.60 (3.17)	9.50 (2.44)	
Procedural	Motor sequence learning	Intervention	13.20 (1.85)	14.40 (2.01)	
		SSAU	13.00 (2.38)	13.10 (3.02)	
	Word identification time accuracy	Intervention	29.40 (3.73)	30.70 (2.84)	
		SSAU	29.45 (2.66)	29.50 (3.34)	
Anxiety	State anxiety	Intervention	40.00 (4.95)	37.15 (5.18)	
		SSAU	41.50 (5.64)	40.25 (6.54)	
	Trait anxiety	Intervention	42.30 (4.23)	39.80 (3.60)	
		SSAU	41.50 (6.97)	41.80 (5.76)	

focus and pay more attention on tasks. There were a few participants (mostly dyslexic participants) who said that they found the memory games in Zing a bit hard to do.

Of the 20 participants in the intervention group, 16 participants completed all the sessions, with the remainder missing occasional sessions due to absence from school. All participants completed both pre-test and post-test.

Effects of the Intervention

Although there were consistent differences between groups in the pre-test, the effects of the intervention condition were mostly similar for each group, and so, except where between-group effects were clear for the effect of the intervention, only the means pooled across the groups will be reported.

Means and standard deviations for DST tasks, across the two time periods, are presented in **Table 2**.

Relative effect sizes for the intervention were calculated independently for each sub-test for the intervention and the

control conditions, using Cohen's *d* adapted for interventions as mean improvement from pre-intervention to post-intervention divided by the overall pre-intervention standard deviation. The results are shown in **Figure 2**, ranked in increasing size for the intervention group.

Two factor analyses of variance, with Phase the repeated measure and Group (Dyslexic vs. non-dyslexic) as the second factor, were undertaken separately for each condition on the effects of the intervention. It should be noted that the Bonferroni correction (which recommends that the 0.05 level be divided by 16, that is $p < 0.003$, to cover 16 multiple comparisons) is not applicable in cases where all changes are in the predicted direction. Nonetheless, for the Intervention analyses, the main effect of Phase was significant at the uncorrected $p < 0.01$ level for 12 tasks, namely (in increasing *F*-value) Bead Threading, Memory Span, Verbal Fluency, Reading, Immediate Picture Recall, Word Identification, Trait Anxiety, Semantic Fluency, Motor Sequence Learning, Postural Stability,

TABLE 3 | Individual changes from initial to final performance on the key tasks (See text for further information).

	Intervention			SSAU		
	Better	Same	Worse	Better	Same	Worse
Postural stability	17 85%	1 5%	2 10%	8 40%	3 15%	9 45%
Motor sequence	16 80%	0 0%	4 20%	9 45%	3 15%	8 40%
Delayed picture recall	17 85%	1 5%	2 10%	4 20%	4 20%	12 60%
Declarative memory	16 80%	0 0%	4 20%	9 45%	1 5%	10 50%
Trait anxiety	14 70%	3 15%	3 15%	11 55%	3 15%	6 30%
Overall ARQ	19 95%	0 0%	1 5%	10 50%	3 15%	7 35%

Declarative Memory, and Delayed Picture Recall with $F_{(1, 19)}$ ranging from 9.10 to 30.83 and η^2 from 0.336 to 0.631 respectively. For the composite At Risk Quotient the overall F was equal to that of Trait anxiety $F_{(1, 19)} = 15.01, p = 0.001, \eta^2 = 0.455$. In terms of the interactions between Phase and Group, 13 tasks showed no effect (max $F = 2.16$). Three tasks showed a clear interaction, namely State Anxiety, Rapid Naming and Verbal Fluency as did the composite ARQ— $F_{(1, 19)} = 4.44, p = 0.049; F_{(1, 19)} = 6.90, p = 0.017; F_{(1, 19)} = 9.52, p = 0.006; F_{(1, 19)} = 11.81, p = 0.003$, respectively. In all four cases the group with dyslexia showed greater improvement.

By contrast, for the SSAU group the main effect of Phase did not reach the $p < 0.05$ level.

Finally, inferential tests were undertaken separately on the relative improvement for the intervention group compared with the SSAU group for the five key tasks -Declarative Memory, Delayed Picture Recall, Motor Sequence Learning, Postural Stability, Trait Anxiety, together with the overall DST-S ARQ. A three factor design was utilized, with repeated measures on Phase (Start vs. End), and independent groups on Group (Dyslexic vs. non-dyslexic) and Condition (Intervention vs. SSAU). A Bonferroni correction for the five multiple comparisons was undertaken, thereby adopting a significance criterion of $p \leq 0.01$.

For Postural Stability there was a highly significant main effect of Phase [$F_{(1, 36)} = 11.78, p = 0.002, \eta^2 = 0.247$] and a highly significant interaction between Phase and Condition [$F_{(1, 36)} = 14.47, p = 0.001, \eta^2 = 0.287$]. The interaction between Phase and Group and the three way interaction between Phase, Group, and Condition were non-significant (maximum $F < 1$).

For Delayed Picture Recall the main effect of Phase did not reach the adjusted criterion [$F_{(1, 36)} = 6.01, p = 0.019, \eta^2 = 0.143$]. There was, however, a highly significant interaction between Phase and Condition [$F_{(1, 36)} = 27.10, p = 0.000, \eta^2 =$

0.429]. The interaction between Phase and Group and the three way interaction were not close to significance ($F < 1$).

For Declarative Memory the main effect of Phase was significant [$F_{(1, 36)} = 7.49, p = 0.010, \eta^2 = 0.172$]. There was a highly significant interaction between Phase and Condition [$F_{(1, 36)} = 12.46, p = 0.001, \eta^2 = 0.257$]. The interaction between Phase and Group and the three way interaction were not close to significance ($F < 1$).

For Trait Anxiety the main effect of Phase did not quite reach the adjusted significance level [$F_{(1, 36)} = 6.17, p = 0.018, \eta^2 = 0.146$]. There was, however, a significant interaction between Phase and Condition [$F_{(1, 36)} = 8.71, p = 0.006, \eta^2 = 0.195$]. There was not a significant interaction between Phase and Group [$F_{(1, 36)} = 82.96, p = 0.09$] and the three way interaction was not close to significance ($F < 1$).

For the Motor Sequence Learning the main effect of Phase was significant [$F_{(1, 36)} = 9.92, p = 0.003, \eta^2 = 0.173$] and the interaction between Phase and Condition did not quite meet the adjusted criterion [$F_{(1, 36)} = 4.88, p = 0.034, \eta^2 = 0.119$]. There was no significant interaction between Phase and Group ($F < 1$). The three way interaction was not close to significance ($F < 1$).

Finally, for the composite DST-S ARQ the main effect of Phase was significant [$F_{(1, 36)} = 36.60, p = 0.000, \eta^2 = 0.504$] and the interaction between Phase and Condition was also significant [$F_{(1, 36)} = 10.56, p = 0.003, \eta^2 = 0.227$] as was the interaction between Phase and Group [$F_{(1, 36)} = 9.94, p = 0.003, \eta^2 = 0.216$]. The three way interaction was not close to significance ($F < 1$).

In terms of the anxiety categorization, the number of participants classified as high state anxiety dropped from 11 (55%) to 6 (30%) for the intervention condition and dropped from 14 (70%) to 8 (40%) for the SSAU condition. The number with high trait anxiety dropped from 10 (50%) to 6 (30%) for the intervention condition and remained at 8 (40%) for the SSAU condition.

The individual changes in performance on these five key tasks (plus ARQ) are shown in **Table 3**. It may be seen that the significant group interactions between Phase and Intervention condition also applied at the individual level, with at least 70% of the intervention individuals improving for each task, whereas mostly equal numbers improved and deteriorated for the SSAU individuals. Furthermore, all 20 of the intervention group improved on at least three of the six tasks, 18 (90%) improved on at least 4, and 13 (65%) improved on 5 or more. The corresponding numbers for SSAU were 9 (45%), 6 (30%), and 2 (10%) for 3+, 4+, and 5+ respectively.

DISCUSSION

In the introduction we stressed the importance and interdependence of three functional dimensions—physical well-being, cognitive well-being and affective well-being—in human performance, and outlined the evidence that adolescents at risk of school dropout might be at risk on all three dimensions in addition to their overt risk of academic failure. We further noted that some interventions might have benefits on at least two dimensions, and that the “cerebellar challenge” exercises might have benefits on all three. This study investigated these three functional dimensions for adolescents at risk of school failure by administering a wide-ranging set of measures, before and after a short cerebellar challenge intervention. The initial tasks revealed that in addition to their difficulties with academic performance, the participating adolescents did indeed show abnormally high levels of anxiety, with those with dyslexia showing still higher overall levels. Their performance on measures of declarative memory and working memory (critical for school performance) were also well below average levels for their peers—again with the dyslexic group performing less well than the non-dyslexic group, indicating weak cognitive well-being. Third, their performance on measures of balance and bead threading were again well below normal levels.

The remainder of the discussion addresses four questions: was the intervention successful; if so, why was it successful and for whom; what are the limitations of the study; and what are the implications for further research and practice?

The results of the intervention were very promising. Both groups had equal time on an “intervention”—Zing vs. SSAU—but of course both groups were selected for being at risk of dropping out from school, and so it is no surprise that the SSAU group performance remained essentially unchanged aside from practice effects on some tasks such as semantic fluency. Clearly, in order to undertake a full randomized controlled trial, a further active intervention group would be required, but it should be stressed that the current “quasi experimental design” gives a direct assessment of the benefits that the Zing intervention gives compared with SSAU, and is therefore of immediate applied interest.

Comparing after-intervention with before-intervention performance for the Zing group, the participants—as a group

and as individuals—improved their performance on all measures except Writing and Spelling. In particular, their performance improved significantly on all five key tasks chosen to cover the “whole person” range of academic, cognitive, physical and affective status. By contrast there were no such benefits for the SSAU group. There was also evidence of a progressive effect, with the dyslexic group improving more than the non-dyslexic group on three measures: Rapid Naming, Verbal Fluency, and ARQ.

We next turn to a discussion of the potential underlying causes of this “whole person” benefit of the intervention. First it is important to acknowledge the likely contribution of generic effects, from Hawthorne effects to benefits outlined above for interventions such as Growth Mindset, academic engagement, systematic progression with feedback, autonomy and perhaps just the rekindling of self efficacy and hope. These are of immense immediate and continuing benefit to each individual, and we have no wish to diminish their importance.

It is important, however, to consider more specific possible benefits, attributable to the type of intervention. As noted earlier, the Zing intervention at heart is a variant of coordinative activity involving an additional, distinctive, “cerebellar challenge” component via vestibular exercises. The coordinative challenge literature highlights the benefits to the hippocampus and hippocampal circuitry. These circuits underpin declarative learning and memory, and therefore the improvements in the school-critical ability to retain information over 20 min (Delayed Picture Recall) and the ability to extract detail from complex information (Declarative Memory) are therefore as predicted. It was also predicted the balance exercises would lead to improved balance performance, as reflected by the great improvement in Postural Stability. However, it is also important to note that the Postural Stability test is completely different from the Zing activities, requiring the participant to adjust rapidly to a push in the back, with and without a blind-fold, and good performance therefore requires rapid adjustment to proprioceptive feedback, a specific function of the cerebellum (Doyon et al., 2003). It is also noteworthy that the Bead Threading performance improved significantly for the intervention group, reflecting a type of improvement not normally attributed merely to motivational effects.

Finally, we consider the significant reduction in trait anxiety of the intervention group. This is, of course a highly desirable outcome, and one that might reasonably be attributed to generic benefits of greater engagement and hope, as discussed above. It is worth noting, however, that there is longstanding evidence of cerebellar involvement in affective state, with the “Cerebellar Cognitive Affective Syndrome” (Schmahmann and Sherman, 1997) being highly influential, see Bodranghien et al. (2016) for a recent synthesis. Of particular interest, a recent study (Zhang et al., 2020) established a clear link between trait anxiety and neural circuitry linking the right cerebellum with the right hippocampus and right parietal lobe in terms of impulsivity. Furthermore, the recent discoveries of intrinsic connectivity neural circuits (Buckner et al., 2011; Bernard et al., 2012) highlight the role of the cerebellum in most of these circuits. Finally, the establishment of clear anatomical linkage between

cerebellum and hippocampus (Watson et al., 2019), added to the anatomical linkage between cerebellum and basal ganglia (Bostan and Strick, 2018) reinforce the claim that unexpected vestibular input can activate the whole brain and body.

It is now necessary to address the significant limitations of this study. First of course, the number of participants was not large, there was no active control condition, and therefore the study is not able to address the underlying causes with certainty; and there were no follow up evaluations to assess the continuing effectiveness of the intervention. All these are legitimate concerns, highlighting the need for further research to fully investigate the effectiveness of this type of intervention. Nonetheless, there are mitigating factors: the participants sampled were selected by the school rather than the investigators, and assignment to intervention Condition was random. There was no participant drop out during the study period, and therefore no possibility of selective withdrawal. The intervention itself was considerably shorter and less intense (30 min on 3 days per week for 8 weeks) than recommended by the Zing Performance team (10 min, twice daily for 6 months). It would therefore have been valuable to evaluate the additional benefits of continued intervention. Unfortunately this was not possible owing to logistical constraints, but the benefits obtained with this study indicate that a short intervention can be effective and practicable within a school environment.

In summary, we advanced the argument that in addressing the needs of adolescents at risk of school dropout one needs to take a “whole person” approach, considering physical well-being, cognitive well-being, and affective well-being. The intervention administered here proved beneficial on all three dimensions for adolescents at risk of school dropout, and has the potential for widespread use.

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DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by University of Sheffield, Department of Psychology Ethics Committee. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

PB had a stronger focus on the empirical work. RN had a stronger focus on design and theoretical interpretation. All authors contributed to all aspects of the empirical work, the data analysis, and the article writing. All authors contributed to the article and approved the submitted version.

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