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Article

# Computer-based cognitive training for cognitive development of alcohol-exposed children in South Africa: a feasibility randomised control trial

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## Abstract

Children exposed to alcohol in utero may suffer from cognitive and physical sequelae. The most impactful damage in terms of daily functioning is to higher order cognitive functions involved in planning and goal-directed behaviour, referred to as executive functions. Cognitive training interventions are used as a remedial tool for executive function deficits but require implementation by professionals. For the South African context, where resources are limited, a tablet computer-based cognitive training game was developed. This study aimed to establish the feasibility of implementing and evaluating this intervention in South Africa for children exposed to alcohol prenatally. This was a three-arm feasibility randomised control trial comparing an alcohol exposed intervention arm, to an alcohol exposed control arm, and a non-exposed normative arm. Arm allocation was based on self-reported maternal alcohol use during a structured interview. To assess feasibility, we evaluated participant recruitment and barriers to implementation. Executive functions were measured at baseline and following intervention to evaluate the preliminary impact of the intervention. No significant differences were found between the three arms on the post-intervention assessments. The retention rate was acceptable for a randomised control trial; however, there was significant variance in the length of time spent playing the game overall. The

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majority of participants learned to play the game quickly and progressed through the difficulty levels. In conclusion, a full randomised control trial using the recruitment, randomisation and implementation method would be suitable in the South African context. The statistical outcomes of this trial do not support a full-scale randomised control trial of this intervention.

**Keywords**
Cognitive training, computer-based cognitive training, executive functions, feasibility study, Foetal alcohol spectrum disorder, prenatal alcohol exposure

## Introduction

Children exposed to alcohol in utero may suffer from cognitive and physical sequelae due to its teratogenicity (Delaney-Black et al., 2003; Riley et al., 2011). Disorders associated with prenatal alcohol exposure (PAE) are grouped under the diagnostic umbrella of foetal alcohol spectrum disorders (FASDs). The impact of PAE varies in presentation and can include dysmorphic growth, stunted growth, birth defects and central nervous system (CNS) abnormalities. The CNS impact is associated with cognitive and behavioural deficits (Coriale et al., 2013; Muralidharan et al., 2013). Even low to moderate levels of alcohol use can have long-term negative outcomes (Noor & Milligan, 2018).

For daily functioning and life outcomes, the most impactful CNS damage is to higher order intellectual functions. These are involved in planning and goal-directed behaviour and include attention and executive functions (EFs; Mattson et al., 2019; Rasmussen et al., 2006, 2012). EFs and attention are fundamental in memory and learning (Diamond, 2013), language development (Mattson et al., 2019), mathematical abilities (Diamond, 2013), and social and emotional processing (Åse et al., 2012). Dysfunction in EF can lead to behavioural problems, mental disorders, poor academic outcomes, difficulties in daily functioning (Diamond, 2013; Fuglestad et al., 2015), and are a key feature of the CNS damage caused by PAE (Kingdon et al., 2016).

Cognitive training (CT) interventions constitute a remedial tool to improve EF. These interventions are especially effective in conjunction with parental and metacognitive strategy training (Kerns et al., 2016; Makela et al., 2019; Petrenko & Alto, 2017). Metacognitive strategies teach techniques to effectively allocate cognitive resources, for example, repeating information to keep it in working memory (Kerns et al., 2016). Children with delays in EF show improvements due to training that tend to be more pronounced than for typically developing children (Diamond, 2013).

The utility of CT outside of research settings has been questioned (Harvey et al., 2018; Lintern & Boot, 2021; Sala & Gobet, 2019). While it improves performance on the specific tasks trained, the extent to which this translates into improvements in other areas is unclear. For CT to be effective, training in a specific task should lead to improvement in other tasks in the same domain (near-transfer) and ideally to improvements in untrained domains (far-transfer). Whether this is possible and the extent of the impact on day-to-day functioning are unclear (Green & Newcombe, 2020; Lintern & Boot, 2021; Sala & Gobet, 2019). In clinical populations, there are significant practical barriers to effective training, including treatment adherence, and a lack of real-world improvement in cognitive function (Henshaw et al., 2022; Marcelle et al., 2018).

Existing remedial training methods require professionals to implement the interventions (Petrenko & Alto, 2017), and traditionally CT consists of therapist-led pen-and-paper cognitive exercises. In high-income countries these professionals can include clinical psychologists (Kerns et al., 2016), occupational therapists (Wagner et al., 2018), and trained educational assistants

(Kerns et al., 2017). In resource-constrained settings, opportunities for remediation are lacking. In South Africa, which has the highest prevalence of FASD globally (Lange et al., 2017; May et al., 2013 M. Urban et al., 2008), there is a lack of health and educational resources (Du Plessis & Mestry, 2019; Zihindula et al., 2019).

The benefits of using technology for CT include decreased cost (Garrido et al., 2017), improved accuracy and efficiency of data capturing (Hufford et al., 2002), and the ability to provide more tailored interventions (Faria et al., 2019). Computer-based CT games have been identified as a promising avenue of intervention (Bahana et al., 2018; Lumsden et al., 2016). CT games can be intrinsically motivating to play and can support scaffolding of improvement by adapting the difficulty of tasks to a user's performance (Hessl et al., 2019; Scott et al., 2020).

CT programmes could provide a valuable remedial resource for FASD. Game-based interventions would require little outside assistance as play would be self-directed. If a CT game can improve cognitive development, without requiring trained professionals, it would be easier to scale up in a resource-constrained environment. For self-directed use without professional support, an intervention must be simple enough for parents and caregivers to understand and be able to teach their children how to play. In resource-poor areas, cost can be a significant barrier to entry and the evidence-based programmes available can be prohibitively expensive. Considering these requirements, a CT game was developed specifically for the South African context (Louw et al., 2019). During the evaluation, we were interested in the feasibility of participant recruitment, intervention delivery, and participant retention. In addition, we investigated the suitability of the neurodevelopmental assessment and maternal interview to identify alcohol exposure. Significant outcomes could also be used to estimate the required sample size for a full RCT.

Identifying a sufficient number of children diagnosed with FASD for an RCT was not feasible, therefore confirmed alcohol exposure during pregnancy was used as a proxy for the damage associated with FASD, although all children exposed to alcohol during pregnancy would not necessarily present with cognitive delays and disabilities. The primary aim of this study was to establish the feasibility of implementing a tablet-based CT intervention for children affected by prenatal alcohol exposure in a resource-constrained environment. The secondary aim was to establish if the method used in this article would be suitable to conduct a full-scale RCT of such an intervention.

## Method

### Participants

The study was conducted in the Saldanha Bay Municipality, 150 km from Cape Town, with a population of around 120,000 people. There is significant income inequality in the area and a 17% unemployment rate among active job seekers (Saldanha Bay Municipality, 2019). The prevalence of FASD is 64/1000 (M. F. Urban et al., 2016).

*Participant identification, recruitment, and retention.* This study focused on children exposed to alcohol in utero. Interventions focusing solely on children with FASD may overlook alcohol-exposed children not meeting diagnostic criteria but still in need of intervention (Viljoen et al., 2018). We identified participants in collaboration with preschools in the area. Mothers of children enrolled at the preschool were approached by preschool principals regarding participation. Study community workers (CWs) obtained informed consent from mothers. Twenty-seven preschools agreed to participate. All consenting mothers were interviewed at one preschool, before moving on to another preschool. The required sample size was reached after interviewing mothers at 14 preschools. The remaining 13 preschools were excluded from the study.

**Table 1.** NEPSY-II subtests per domain.

| Attention/ executive function | Language | Memory/learning |
|---|---|---|
| Statue (ST) | Comprehension of instructions (CI) | Memory for designs (MD) |
| | | MD: Spatial (MDS) |
| | | MD: Content (MDC) |
| | | Narrative memory free and cued (NMFC) |
| | | Narrative memory and recognition contrasted (NMR) |
| | | Sentence repetition (SR) |

To participate, a mother needed to have a biological child between 4 and 6 years old, enrolled at a local preschool. By the age of 4 years, the EFs of interest are measurable (Anderson, 2002), and children are required to enter primary school in the year they turn 7 (Department of Education, 1998). Allocation into the three arms of the study was done based on self-reported alcohol use during a structured interview. The interview was developed for FASD epidemiological studies and has been used extensively in South Africa (M. Urban et al., 2008; M. F. Urban et al., 2015, 2016). The interview also covered sociodemographics and health behaviour during pregnancy. Alcohol exposure was defined as exposure to three or more standard units of alcohol on one or more occasions during pregnancy (Hoyme et al., 2016). If this was confirmed, mothers were randomised into an intervention or control arm. Participants who did not meet this threshold were randomised to either be included in a normative arm or to be excluded from the study.

*Sample size.* To estimate a suitable sample size for future trials we used previous CT interventions for children with FASD, which generally showed medium effect sizes (Coles et al., 2009; Kerns et al., 2016; Nash, 2012; Schaffer & Geva, 2015). As the current study was a feasibility RCT, we remained conservative and used a small ($d = 0.2$) effect size. With a significance level of .05, a sample of 120 participants would yield statistical power of 0.79 for the planned repeated measures multivariate analysis of variance (MANOVA) measuring differences with 40 participants per arm ($N = 120$; Louw et al., 2019).

## Instruments

As EFs are sensitive to change in children with FASD, we used measures of EF as a proxy for cognitive development. EFs were measured using the NEPSY-II neurodevelopmental assessment (Korkman et al., 2007). The NEPSY-II is a battery of individually administered subtests that are selected based on the domains of interest (Davis & Matthews, 2010). It has been used in studies of EF in children with FASD (Nash et al., 2015; Rasmussen et al., 2012). It has also been used in low- and middle-income countries (LMICs) (Mulenga et al., 2001), including South Africa (Dalen et al., 2007; Rochat et al., 2019). See Table 1 for an overview of the subtests administered.

To assess the feasibility of implementation, we looked at ease of participant recruitment, and barriers to implementation. We explored whether children could successfully engage with the tablets and complete game tasks. To evaluate the self-directed play, we recorded total play sessions and the number of trials completed per session.

*Game design.* Game tasks were designed to induce neuroplasticity by requiring the effortful use of EF (see Image 1 for an overview of the game interface). The goal for each task was to match a

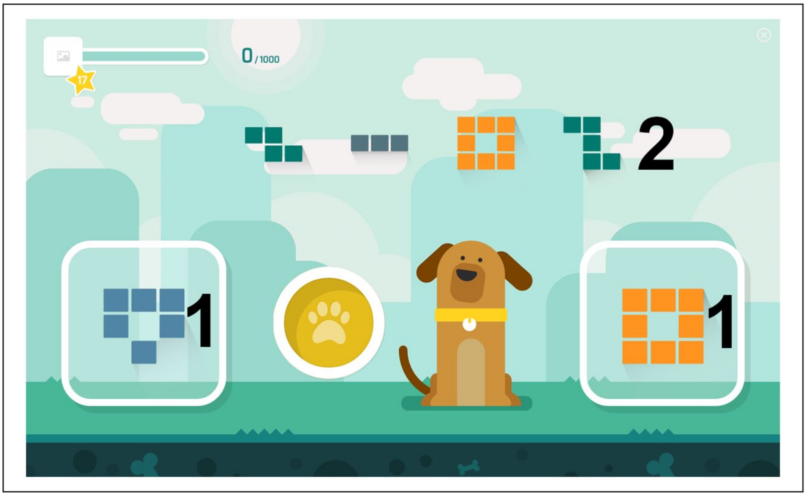


**Image 1.** CT game user interface.

response image, labelled as '1', to a target image labelled as '2'. Tasks did not target a specific EF. Instead, the way response images were displayed relative to target images was varied to target different EFs over time.

## *Procedure*

*Trial design.* This was a three-arm feasibility RCT comparing alcohol-exposed participants receiving the intervention to an alcohol-exposed control arm and a non-exposed normative arm. Participants were allocated to group based on PAE. The non-exposed normative arm was included to test the assumption that alcohol-exposed participants perform worse than their non-exposed peers at baseline (see Figure 1 for study design).

*Randomisation and blinding.* Study IDs were allocated to child participants upon completion of the maternal interview. As alcohol-exposed participants were identified they were randomised into the control and intervention arms using block randomisation. A table with cells pre-allocated to the intervention or control arm was created using random number tables (Rand Corporation, 2001) by the primary investigator (JL). Only the participant's study ID was provided for this process to keep the PI blinded to the level of alcohol exposure of participants.

Once the intervention and control arms were filled, 40 participants were randomly selected from non-exposed participants for the normative arm. As only the intervention arm interacted with the CWs, it was not possible for them to remain blind to arm membership. The control and normative arms still interacted with the preschool teachers while the intervention group played the game.

*Intervention group.* The intervention was offered in the preschools. The intervention arm received the intervention in addition to the early childhood development (ECD) programmes available at their preschool. At the first play session, children were shown how to play the game by a CW on an individual basis. Once they understood the game mechanics they proceeded at their own pace. If a child was tired of playing or did not want to play, they were allowed to stop.

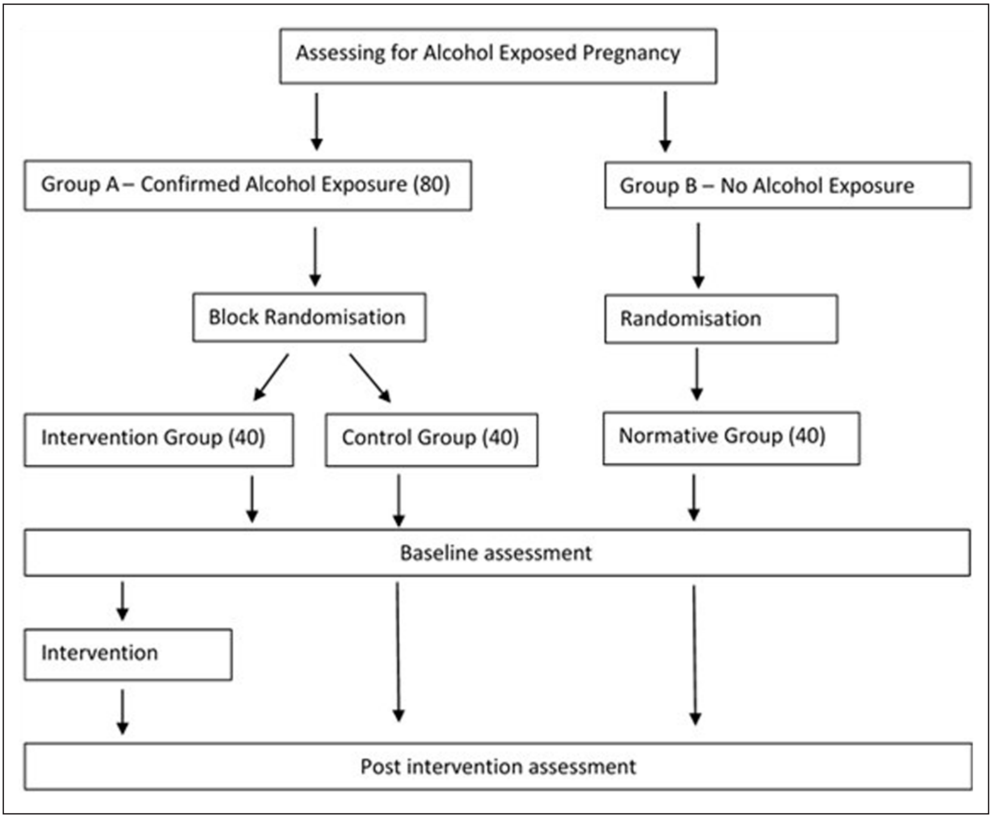


**Figure 1.** Study design.
Source: Adapted from Louw et al. (2019).

CWs oversaw participants' play sessions at the preschool where they were enrolled. Children engaged with the tablet in a designated area away from classroom activities. CWs provided the tablets to be used and each child played on a specific tablet for the duration of the session. Tablets were used by more than one participant; therefore, the CWs would ensure participants had the correct tablet using pictures of participants stored on the device.

CWs were present but provided no guidance to participants. The interaction was limited to encouraging participants to play if they became distracted. Their role was to provide oversight so that the teachers would not have to watch the participants. Other CT interventions for FASD have shown impact in 12 weeks, however, as this intervention was self-directed the protocol called for 48 play sessions over 6 months. Sessions were to be held twice per week and children could play for an hour per session.

*Control and normative arms.* Children in the control arm or normative arm did not receive any intervention. They were assessed at baseline with no further interaction with CWs until the intervention finished. They still attended the preschool and participated in its regular activities continuing to receive the standard developmental support. They received the follow-up assessment at the same time as the intervention group.

### Ethical considerations

Ethics approval was obtained from the Health Research Ethics Committee at Stellenbosch University (Reference #: N16/05/063). The study was also registered with the ISRCTN (ISRCTN17244156). Mothers of participants provided informed consent for their child's participation.

### Data analysis

Standardised scores were used for the analyses of NEPSY-II outcomes. The primary outcome was measured using the post-intervention scores. These scores were compared across the intervention, control, and normative arms. Maternal alcohol use was compared in the two alcohol-exposed arms (intervention and control) by calculating the mean number of standard drinks. Demographic equivalence of the three arms was assumed based on randomisation. This assumption was evaluated using chi-square tests and one-way analyses of variance (ANOVAs). Cognitive development was also compared between the arms at baseline. The impact of the intervention was measured using a MANOVA with arm membership as the predictor variable and post-intervention scores as outcome variables. To account for possible violation of some assumptions of a MANOVA, Pillai's trace was used as the test statistic, and it was analysed at a conservative level of $\alpha = .01$. Assessment scores were interpreted for each arm using suggested classification tables (Miller, 2012).

## Results

### Eligibility recruitment and consent

Mothers approached by preschool principals were amenable to participation. A total of 235 interviews were conducted to recruit the required number of participants. Upon review, it was discovered that four participants were younger than 4 years and were thus excluded. One of these participants was in the intervention arm and three were in the control arm. There was a total of seven participants lost to follow-up. These participants were in the control ($n = 1$) and normative ($n = 6$) arms. See the CONSORT diagram (Figure 2) for a detailed participant flow diagram. The trial ended when all participants had been given the opportunity to complete the maximum of 52 sessions. There were no adverse events reported during the trial. Four participants exceeded the maximum number of sessions but were included in the analyses as the overall number of trials they completed fell within the range of the trials completed by other participants as they completed fewer trials per session on average.

The average age of the children was 4 years and 8 months, and the average age of the mothers was 29 years and 11 months (range 20–46 years). At the time of their child's birth mothers were on average 25 years and 1 month old (range 15–42 years). The mothers had a median of two children with a maximum of five children. There were 31 children living with no other children in their household, and two children lived in households with a maximum of six children.

### Demographic comparison

Comparing alcohol-exposed and non-exposed participants, the sample was generally homogeneous with no concerning differences found during the analyses. The possible confounding variables of

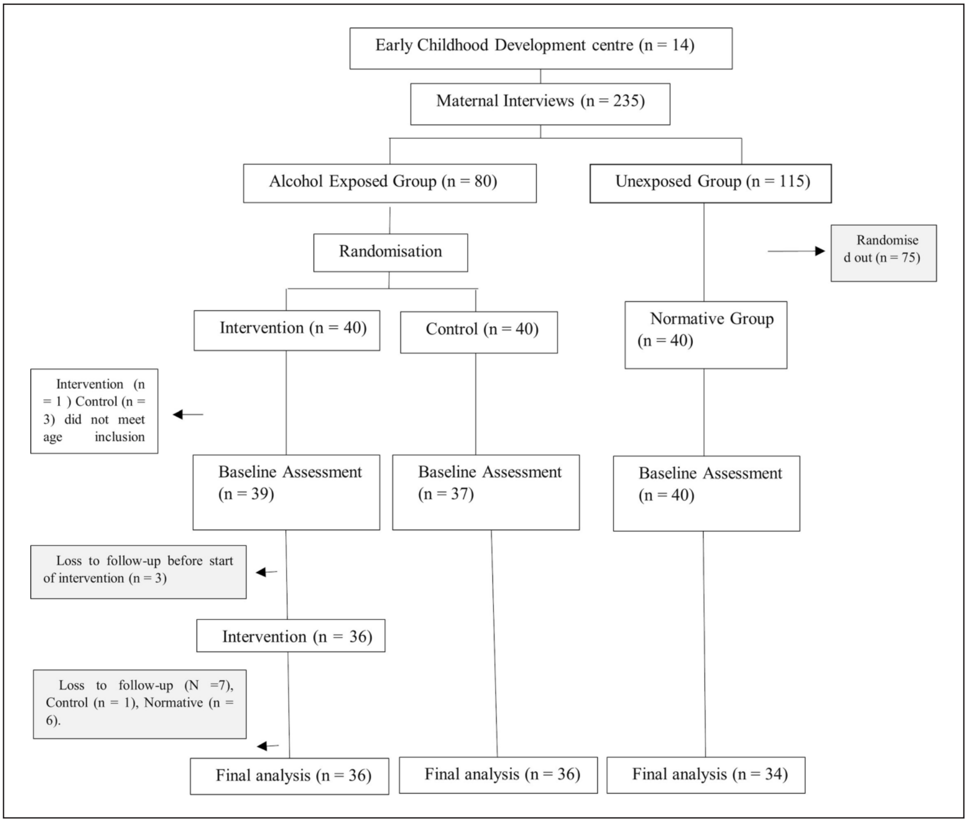


**Figure 2.** CONSORT diagram.
Source: Adapted from Louw et al. (2019).

monthly household income (mean difference ZAR 690.62, 95% confidence interval [CI]: −1259.95, 2641.18, $t_{108}=0.702$, $p=.48$), receiving government support grants (alcohol-exposed: 59/76, 78%; non-exposed: 25/40, 62%; $\chi^2_1=3.00$, $p=.08$), and caregiver unemployment (alcohol-exposed: 24/76, 30%; non-exposed: 16/40, 40%; $\chi^2_1=1.01$, $p=.32$) showed no significant differences.

## *Intervention barriers*

All of the preschools approached were willing to participate in the study, and the teachers were supportive, making space available and supporting the CWs in terms of scheduling and making the children available at the requested times. No participants withdrew during the study, and the children seemed to understand how to operate the tablets. Due to delays in the game's development, the timeline of the intervention was pushed back which had a knock-on effect on the start of the intervention. The intervention was therefore interrupted by school and public holidays. To lessen the impact of these interruptions additional sessions were allowed up to a maximum of 52 sessions.

Only six participants in the intervention group completed the total number of sessions. On average, participants completed 37 play sessions. This fell far short of the proposed 52 sessions. During play sessions, participants completed an average of 137 trials per session (range of 100–194). The post-intervention assessments were completed on average 11 months after the baseline assessment.

**Table 2.** Between-participant effects with arm membership as a predictor variable.

| | Type III sum of squares | *df* | *F* | Partial $\eta^2$ | *p* |
|---|---|---|---|---|---|
| Comprehension of Instructions (CI) | 27.624 | 2 | 1.513 | .031 | .225 |
| Memory for designs (MD) | 0.101 | 2 | 0.008 | .000 | .992 |
| MD: Content (MDC) | 8.950 | 2 | 0.597 | .012 | .553 |
| MD: Spatial (MDS) | 0.286 | 2 | 0.014 | .000 | .987 |
| Narrative memory free and cued (NMFC) | 14.136 | 2 | 0.689 | .014 | .504 |
| Narrative memory and recognition contrasted (NMR) | 15.212 | 2 | 0.547 | .011 | .581 |
| Sentence repetition (SR) | 0.269 | 2 | 0.029 | .001 | .971 |
| Statue (ST) | 68.008 | 2 | 3.650 | .071 | .030 |

An average of 25 days elapsed between a participant's final play session and assessment ($SD=29.23$), with a maximum of 152 days and a minimum of 2 days.

### *Outcome assessment*

There were no significant differences between the three arms on the post-intervention assessments, V=.187, $F(16,180)=1.157$, $p=.307$. All three arms performed below the expected age norms at baseline (see Table 2 for between-participant effects). Mean difference (*Mdiff*) scores for each subtest, pre- and post-intervention, were compared separately for each arm. Two outcomes were significant after applying a Bonferroni correction to the paired sample *t* tests. The control arm showed improvement in the comprehension of instructions subtest (*Mdiff*=1.56, $SD=2.37$ 95% CI: [0.75, 2.36]), $t(30)=4.453$, $p<.001$. The normative arm showed improvement in NMFC (*Mdiff*=2.07, $SD=2.58$ 95% CI: [1.12, 3.01]), $t(35)=3.935$, $p<.001$. Post-intervention assessments were conducted 11 months ($M=10.93$; $SD=0.255$) after the baseline assessments.

## Discussion

This study aimed to establish the feasibility of implementing and evaluating a cognitive training game developed for children exposed to alcohol in utero. While the identification and recruitment of participants through referrals by preschools were highly successful, the implementation and evaluation of the game met with mixed success. A full RCT using the game in its current form and using the same assessment tools is not supported.

### *Eligibility recruitment and consent*

Referral through preschools was successful in this context where there is a high prevalence of alcohol use during pregnancy. The inclusion criteria of alcohol exposure at a clinical level of three standard drinks, did not prove to be a barrier to recruitment as mothers appeared to be open about alcohol use.

This ease of recruitment may not hold true in all contexts, especially where the prevalence of alcohol use during pregnancy is lower, or where the stigma regarding alcohol use during pregnancy is more severe. If the population of interest was individuals diagnosed with FASD, reaching the desired sample size would be more difficult. Diagnosed individuals would likely need to be drawn from multiple communities. A strength of this study was the demographic similarity between the three arms in the trial.

## Participant retention

The retention rate was acceptable for an RCT; however, there was significant variance in the number of trials and sessions completed by participants. Uptake and retention are generally good in resource-poor environments as opportunities are scarce, and as it was delivered at a preschool, practical barriers like a lack of transportation were not a concern. For a full-scale RCT, the target number of trials and sessions required for successful completion would need to be more clearly defined.

## Intervention barriers

The most significant barriers to delivering the intervention were linked to the closing of pre-schools over holidays. This caused delays in the completion of the intervention and stretched the time over which the sessions were done. This could have impacted the effectiveness of the intervention. In terms of individual participants, none of the children met the exclusion criteria of having a physical disability that would make it difficult to interact with the tablet. The majority of participants learnt to play the game quickly and progressed through the difficulty levels. As the current iteration of the programme did not show any impact, it is likely a redesign would be required before future trials.

## Outcome assessment

There were no differences in cognitive functioning between the three arms at baseline or post-intervention. The most obvious conclusion from this is that the game simply did not measurably improve the cognitive development of children, as with similar cognitive training games aimed at improving EF (De Vries et al., 2015). It is possible that there were improvements in functioning that were not picked up by the NEPSY-II due to it not being sensitive enough to pick up on improvements limited to specific cognitive functions. A future trial would benefit from a more suitable assessment of EF, but at present no such assessments are normed for South African populations. A further explanation could be that there were children included in the non-exposed normative group who were also exposed to alcohol prenatally which could impact on comparative analyses. The current study showed no significant pre and post differences in the intervention group. In addition to changes in the implementation of the intervention, it would be of value to re-evaluate the design of the game itself.

## Limitations

While participant identification and recruitment were successful, it may be more difficult in larger populations where preschools are not as easily accessible. The study population was open and willing to discuss alcohol use. However, in communities characterised by greater levels of stigma towards alcohol use, relying on self-reported alcohol use would be a limitation. Desirability bias may still have led to the underreporting of alcohol use, and it is possible that participants in the non-exposed arm were in fact alcohol exposed. Using alcohol exposure as a proxy for damage associated with FASD was a limiting factor as all children exposed to alcohol do not necessarily present with cognitive deficits. In terms of evaluating the effectiveness of the intervention, the major limitations were the lack of normed assessments of EFs for South African populations. The variability in the time elapsed between a participant's final play session and their post-intervention assessment is also a limitation as improvement in cognitive function may decrease over time. For this feasibility study, the design limitations of the intervention are not a limitation, but it would be for a full RCT.

## Conclusion

In terms of trial feasibility, the setting, recruitment, and randomisation elements worked well and posed no significant challenges. Given the limited resources, it is unlikely that a large enough sample of children diagnosed with FASD who are of a similar age could be recruited with similar ease. For future trials, we strongly suggest using this strategy to reach participants.

Implementation of the intervention was less straightforward with delays in intervention implementation. Future trials should evaluate whether a shorter time frame would be better suited to the context. It may also be better for the entire intervention group to be randomised at the start of the intervention and not be staggered as with block randomisation. The aim of this study was not to evaluate the overall effectiveness of the intervention. However, the lack of any significant difference in the pre- and post-assessments suggests that the intervention itself could require a redesign. Given the drop-off in interaction over time, the aim of a redesign would be increasing long-term engagement with the programme.

In conclusion, a full-scale RCT of a CT game using the recruitment, randomisation and implementation method would be suitable in the South African context. The implementation would need careful planning to avoid pitfalls identified in this study. The statistical outcomes of the CT game used in this study strongly suggest however that an intervention using the game in its current format would not warrant the expense of a full-scale RCT.

### Declaration of conflicting interests

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