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Tablets for two: How dual tablets can facilitate other-awareness and communication in learning disabled children with autism

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ABSTRACT

Learning-disabled children with autism (LDA) are impaired in other-awareness, joint attention and imitation, with a poor prognosis for developing language competence. However, better joint attention and imitation skills are predictors of increased language ability. Our study demonstrates that a collaborative activity delivered on a novel dual-tablet configuration (two wifi-linked tablets) facilitates active other-awareness, incorporating imitation and communicative behaviour, in 8 LDA boys with limited or no language, aged 5–12 years. LDA children did a picture-sequencing activity using single and linked dual tablets, partnered by an adult or by an LDA peer. Overall, the dual-tablet configuration generated significantly more active other-awareness than children sharing a single tablet. Active other-awareness was observed in LDA peer partnerships using dual tablets, behaviour absent when peer partnerships shared a single tablet. Dual tablets facilitated more communicative behaviour in adult–child partnerships than single tablets. Hence, supporting collaborative activities in LDA children can facilitate other-awareness and communicative behaviour and adult and peer partnerships make different, but essential contributions to social-cognitive development through the collaborative process.

1. Introduction

Autism is a Spectrum Disorder, highlighting the fact that the level of impairment experienced by people affected by the condition can vary greatly. Intellectual disability (ID) is very commonly associated with autism, with approximately 70% of individuals diagnosed with autism also having ID. An individual is considered to have an ID with an IQ < 70 and ID can be separated into three groups; mild ID, IQ 55–69, moderate ID, IQ 40–54 and severe ID < 40 [1]. Of the 70% of individuals diagnosed with autism and ID, about one third will have a mild to moderate ID and another third severe to profound [2–4].

The long-term outcome of individuals diagnosed with autism and ID is very poor, with only a small minority of individuals with IQs less than 50 achieving a high level of independent functioning by adulthood and the majority remaining dependent on their families and the state [5]. The long-term outcome for adults with ASD is estimated to cost the UK economy approximately £25 billion annually (Knapp, Romeo, & Beecham, 2009). Therefore, it is crucial to determine how to help learning disabled children with autism (LDA) attain more independent levels of functioning by adulthood.

Technological interventions for children with autism have been popular across levels of age and IQ [6]. However, Parsons [7] notes the need for careful reflection in such design. Parsons and Cobb [8] propose a three-layered design approach of Theory, Technology and Thoughts (3T). They suggest that the top 'Theory' layer should drive design to address the fundamental impairments of interaction and communication found in children with autism. The 'Technology' layer is represented by the 'learner-centred design' of technology to offer affordances designed with specific learning or interaction goals in mind. The base, 'Thoughts' layer should influence the design from the bottom up by incorporating the views and experiences of teachers, parents and children with autism and designing the technology appropriately for the environment where it will be used and hence designed with both the context and the end user in mind [7].

This paper presents the on-going development and evaluation process of a novel computer application (app) designed as a technological intervention to support other-awareness and collaboration in LDA children. Following the 3T approach, we first, introduce the developmental theory underpinning the authors' focus of designing technology to support other-awareness and collaboration in LDA children. Secondly, we illustrate how the design of the technology was learner-centred and informed by the

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collaborative design framework proposed by Yuill and Rogers [9], with the specific goal of facilitating collaboration. Thirdly, we illustrate how the design drew on end-users in a specific context through incorporating the views of teaching staff familiar with the participants during the design process and testing the app in the special school environment.

By their very diagnosis LDA children are impaired in communication and so it is challenging to obtain their views in traditional ways, meaning that these views are not always reflected in design. Some researchers have demonstrated ways of including the views of the autism community during the design process. For example, Parsons and Cobb [10] used workshops, discussions groups and paper and high fidelity prototypes as methods for participatory design and commented that testing the high fidelity prototype in school with the teachers and end users "was important to ensure that technology design was informed by user needs and abilities so that the final product was fit for use in school-based learning" (ibid, p. 5). Frauenberger et al. [11] described a participatory design process that took into account children's feedback using annotator tools for a touch screen computer interface, including smiley and sad faces. The children with autism could indicate the aspects of the digital environment they liked or disliked and the researcher used these external representations of the children's thoughts to initiate discussions. These are good examples of how to include children with autism in a participatory design process where children have some verbal communication abilities.

We propose here two important means of incorporating the views of LDA children with autism who have limited or no verbal ability. Firstly, LDA children can be given contrasting versions of a high fidelity prototype technological intervention to test in the environment in which it will be used and secondly the method of analysis used to assess the effectiveness of the prototype should reflect the fundamental impairment of interaction and communication that the software is aiming to address, and should assess in detail children's behavioural responses to the different software environments. Accordingly, this paper reports on the testing of a prototype technological intervention with LDA children in a special school environment. The main theme of this paper is the comprehensive analysis of LDA children's interactive behaviour compared across two similar technological aids in order to determine what aspects of the environment are more effective for engaging the LDA children and promoting the target behaviours. Fine-grained analysis of LDA children's behavioural responses can be used as a means of gauging their views and reactions. Such analysis of LDA children's responses to technology is both appropriate for testing effectiveness of design to elicit the target interaction goals and also helpful for incorporating the views of LDA children who would be disadvantaged by approaches requiring explicit reflection and verbal skills.

1.1. *Theory: the development of other-awareness and collaboration*

In typically-developing (TD) children other-awareness emerges early in development and can be observed in the face-to-face interactions of mothers and infants from around one month of age [12]. Early social abilities in TD children, such as joint attention and imitation are thought to be intimately related to the development of self and other awareness. From around six months of age a TD child will develop the capacity to include objects in self and other referential cognitions and in social interactions based on joint attention [13]. Joint attention involves the capacity of children to coordinate their attention to include another person and an object. These are complex behaviours that include *responses* to gaze and gestures from another person seeking to share attention to an object or event, and using gaze and gesture to *initiate* the sharing of attention to an object or event with another person [14]. Imitating the actions of another person is a common behaviour that suggests an awareness of the other. Evidence from Killen and Uzgiris [15] suggests that in TD children this may emerge from around $7\frac{1}{2}$ months of age and that imitation is an early emerging social skill used to initiate and maintain social interaction [16]. Eckerman and Didow [17] also found that TD children were more likely to communicate with a peer partner when engaged in coordinated action dominated by imitative behaviour. Therefore, in typical development, other-awareness, joint attention and imitation are found to be the earliest forms of behaviour that support social interaction and communication.

However, children with autism are shown to have impairments in imitation [18,19] and joint attention [20,21]. These impairments are considered fundamental in affecting their long-term outcome, since, in children with autism, better joint attention and imitation skills are robustly associated prospectively with superior language development [22–25,19]. Furthermore, the fundamental abilities of joint attention and imitation are seen as prerequisites for participation in collaborative activities [26] and hence a possible reason for deficits in the capacity of children with autism to cooperate [27]. Moll and Tomasello [28] draw on Bratman's definition of cooperation to advocate the Vygotskian intelligence hypothesis (VIH), that cooperative interaction is the driving force of social cognition. Through cooperative interactions Moll and Tomasello [28] propose a child develops an awareness of the other person and this other-awareness facilitates language, learning and social development. Moll and Tomasello [28] propose that other-awareness emerges from children firstly being able to recognise the sharing of a 'joint' focus of attention with another person, and then, from this triadic awareness, to develop an understanding that another person can have a different perspective of a shared experience. This understanding that others have individual thoughts, beliefs, emotions and intentions is believed to be a critical aspect of social cognition and a primary impairment in autism [29–31]. Therefore, the aim of the design of the app reported in this paper is to facilitate collaboration in order to support the development of other-awareness, joint attention and imitation and ultimately the communication skills of LDA children.

We use the term collaboration as defined by Roschelle and Teasley [32] to describe "a coordinated, synchronous activity that is the result of a continued attempt to construct and maintain a shared conception of a problem" (ibid, 1995, p. 70). In contrast, these authors defined cooperation as a "division of labour among participants, as an activity where each person is responsible for a portion of the problem solving" (ibid, 1995, p. 70). These authors define collaboration as activities that bring about the 'mutual engagement' of participants to solve a problem together, in contrast to those that give participants individual problems to solve. This distinction of working on the same problem together compared to having different roles with the ultimate aim of achieving the same goal is consistent with descriptions by Hord [33] and Paulus [34]. The technological design and the activities reported in this paper were designed so that two players have identical tasks to solve, with actions interlinked in a way that necessitates the generation of corresponding representations during the problem solving process, in order to reach a shared solution. We therefore characterise the tasks reported in this paper as collaborative, rather than cooperative.

It is generally accepted that children with autism find computer technology motivating and beneficial to their learning [35–39]. Taking this into account researchers have turned their attention to investigating how shareable computer technology can help support collaboration and the social interactional skills of children with autism. However, there are two general limitations of this literature. First, much of this work relies on the very general assumption that technology is motivating. While this might be

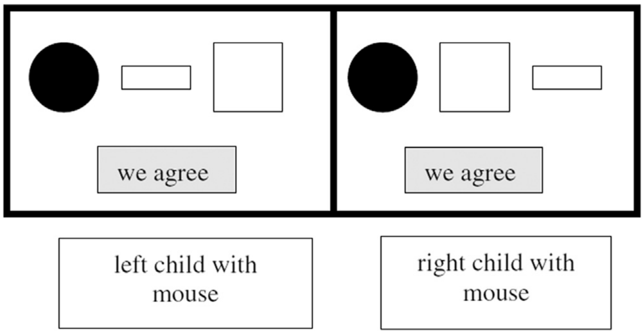

Fig. 1. SCoSS interface showing two identical task configurations on a shared screen with two mice for separate control.
Source: Taken from Kerawalla et al. [40].

true, it is not clear whether this is a novelty effect, and it seems plausible that such effects will diminish or disappear when technology is the default mode of engagement in activities at school. Second, it is not the technology itself, but the forms of practice and design of the technology that affords different sorts of interactions. It is rare for research studies in this area to make direct comparisons of different technology designs, as presented in this paper, rather than just comparing technological aids versus their absence.

1.2. Designing affordances to support other-awareness and collaboration

The app presented in this paper drew on the Separate Control of Shared Space (SCoSS) framework, specifically designed to facilitate collaboration in TD children, by Kerawalla et al. [40], using two mice for dual control of a single computer screen. Kerawalla et al. [40] proposed that users sharing a single interface were more likely to produce cooperative behaviour as tasks are often designed for single use and users cannot easily interact with individual task elements simultaneously. Therefore, it is probable that users will divide up problems and take on individual roles i.e., cooperate to solve a shared problem. It is also possible, when sharing a single user interface for one user to complete a task on their own.

SCoSS (Fig. 1) was designed with 'core properties' to overcome these potential barriers to collaboration by "*the provision of separate control over an identical version of the task for each child, within their own private screen space, that is visible to both participants*" ([40], p. 195).

Thus, users can only control their own task elements, but are able to coordinate their actions with their partner's to interact simultaneously on identical task elements within their own task space. Both users can also see their partner's ongoing task state, which Kerawalla et al. [40] argue provides a resource to stimulate discussion towards solving the shared problem. Users can also be required to agree with each other during the problem solving process by clicking their own 'We agree' button, but this is constrained: they can only proceed if their individual game states show agreement.

Kerawalla et al. [40] presented a qualitative analysis of children's interactions during a word categorisation task using the single or SCoSS interface. They described less equitable input using the single interface and more independent working compared to the SCoSS interface. They propose that the separate working spaces of the SCoSS interface meant children demonstrated disagreement and agreement explicitly and that the requirement to show agreement by pressing 'we agree' 'fostered discussion' thus promoting 'useful educational dialogue' [40]. Yuill et al. [41] provided quantitative evidence of more complex and mature discussions when TD children used SCoSS compared to non-SCoSS. Yuill and Rogers [9] described a framework for designing technology to support collaboration that identifies three mechanisms, all used in SCoSS, that support collaboration: firstly, features to support the awareness of a partner, secondly, using control to support contingency of responses in paired users, and thirdly, increasing the availability of background information by providing cues about previous actions. These features are all present in the current SCoSS-inspired design to support collaboration in joint tasks.

1.3. Designing for LDA children

Holt and Yuill [42] redesigned the SCoSS interface used by Kerawalla et al. [40] with the aim of supporting other-awareness and imitation in LDA children through a collaborative computer activity. To ensure the activities were engaging for the LDA children, Holt and Yuill [42] consulted the teaching staff who worked with the LDA participants The 2×2 word categorisation task used by Kerawalla et al. [40] was simplified to a 2×1 picture categorisation activity and the images used for the activity were selected specifically to appeal to the individual participants, in recognition of the important role of motivation in sustaining participation in children with LDA.

Holt and Yuill [42] compared the frequency of behaviours signalling other-awareness produced by LDA children while doing the revised SCoSS picture-sorting task with a partner (LDA peer and adult), using two mice for dual control of a single or SCoSS interface. Other-awareness behaviour demonstrated by the LDA children was defined as attentional – related to their partner's actions or as active – awareness that was both related to and contingent on the actions of their partner. These authors reported that LDA children only demonstrated active other-awareness of a partner (either peer or adult) when using the supportive SCoSS interface, behaviour that was absent when sharing a single interface. Thus the SCoSS interface offering two identical interlinked game representations, was more effective at supporting other-awareness and collaboration during a computerised picture sorting activity than sharing a single game representation.

The identity of the partner (e.g., peer or adult) can make a difference to the nature of interactions with LDA children, as Holt and Yuill [42] found. For example, in observations of LDA children during free-play and a lunch-time meal setting, Hauck et al. [43] and Jackson et al. [44] found differences in the quality and quantity of spontaneous social interaction between peers and adult teachers. The present study therefore included both peer and adult partnerships, to assess any effects of type of partner on the nature of interactions with both the technology and with the partner.

While encouraging, the Holt and Yuill [42] results have limitations. Firstly, mouse use proved difficult for some of the LDA children in the study, limiting the accessibility of such technology. Touch technology has greatly increased the possibilities for communication and interaction for those with learning disabilities [45]. However, it also presents design challenges to collaborative approaches, since most tablet technology is designed with single users in mind. For example, touch does not identify users and hence does not easily enable implementation of the control or turn-taking constraints afforded by SCoSS. Tablets are widely available and engaging for users of all abilities, with tablet and mobile technology being used increasingly frequently as augmentative and alternative communication aids [45]. This study therefore addressed the challenge of using 'personal' devices to support collaborative interaction. Secondly, the Holt and Yuill study involved a very small sample (2 pairs of LDA children) and assessed a limited range of measures, not including imitation and communication.

Following on from the findings reported by Holt and Yuill [42] of the effectiveness of the SCoSS interface to facilitate collaborative

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Fig. 2. Set up of the single-tablet configuration (left) and the dual-tablet configuration (right).

activity in LDA children with both adult and peer partners, the present study investigates the feasibility of using tablet technology to design a SCoSS-like 'constraint' approach to collaboration with single-user devices, to support engagement, other-awareness, imitation and communication in eight LDA children.

2. Tablet design

In extending the SCoSS architecture to tablet devices, a dual tablet setup was created to allow for individual touch identification. The dual tablets were linked using wireless technology so that the SCoSS framework could be applied to support other-awareness and collaboration. Tablets were arranged side-by-side in two cases on stands (Fig. 2, right) to create a shareable computer environment affording the collaborative features of the SCoSS model described by Holt and Yuill [42]. The collaborative software designed for a dual tablet setup affords the four features offered by SCoSS; 1. Identical tasks to solve. 2. Own task control, provided by an individual tablet. 3. Explicit representation of agreement i.e., the requirement to position task pieces in corresponding positions to a partner's. 4. Control of task progress, by having points in the task where both users have to negotiate an explicit joint agreement about where the task pieces are placed, afforded by clicking the 'We agree' icon and the feedback of the icon flashing red if agreement is not in place and by flashing green and providing the next picture for the task if both users show agreement.

This study compared the behaviour of LDA children presented with a picture-sequencing task in two different tablet configurations: a single tablet, as is typical in classroom use, and dual SCoSS-enabled tablets (Fig. 2), and with two types of partner: a peer or an adult. Picture-sequencing is frequently used in the context of the special school environment to assist LDA children in the structure of their day and as a learning activity. It was hence judged to be an appropriate activity. The teachers were consulted as to what characters would engage the children and picture sequences were designed with this in mind. Engagement is considered a prerequisite of other-awareness: if a child is not engaged then it is impossible to make assumptions as to whether or not other-awareness is in their repertoire. For this reason, LDA children's engagement with the task was also assessed. Engagement involves measures of the children's approach to and withdrawal from, the task. The LDA children's triadic interactions with the technology and a task partner were assessed by measuring their other-awareness, as in [42], in addition to their use of imitation and communicative behaviour.

2.1. Picture-sequencing activity

Five different picture-sequencing tasks were created, depicting a simple sequence of events, using well-known children's characters selected to be attractive to the children (see Figs. 3 and 4). Pictures were presented sequentially in a random order (the same, random sequence appeared in the same condition). Pressing the 'We agree' icon will deliver the first of five pictures to be

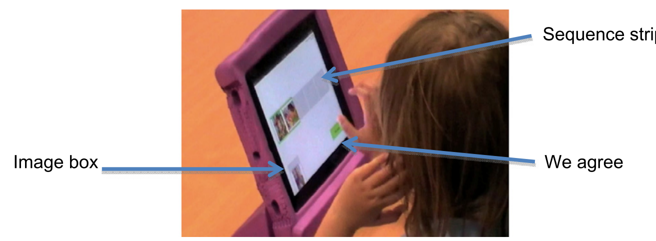

Fig. 3. Single tablet showing one game representation to be shared between two players. Two pictures are placed on the sequence strip and the green border is visible. The 'We agree' has flashed green informing players that a new picture is arriving, shown in the image box. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

sequenced, into the image box (Figs. 3 and 4). The same picture sequence was used for the two practice rounds in each tablet condition, with 4 different picture sequences used for each experimental condition.

2.2. Single tablet

Pairs sharing the single tablet (Fig. 3) can both interact with the interface, although the tablet can only respond to one touch input at a time, thus there are no constraints in place to encourage collaboration. Pressing the 'We agree' icon delivers the first picture into the image box. The picture can be placed anywhere onto the 5-space sequencing strip and then pressing the 'We agree' will deliver another picture into the image box. The pictures do not need to be correctly sequenced in order to progress through the task. Therefore, other than the requirement to place pictures on the sequencing strip there are no other constraints (Fig. 3). Players are free to move pictures already in play throughout the activity.

2.3. Dual tablets

'We agree' icons on both tablets must be pressed to receive the first and subsequent pictures into both image boxes simultaneously (Fig. 4). Players are required to place their picture on to the sequencing strip. The pictures do not need to be correctly sequenced, but they must be placed in corresponding positions on each tablet. When pictures are in 'matching' positions on both game representations, the borders around both players' picture/s will turn green. 'Greenness' informs the players that the game state is correct (Fig. 4). If pictures on both screens of the dual tablets are not in matching positions, pressing the 'We agree' will not generate another picture in the image box and the 'We agree' icon will flash red informing players that they are incorrect. The picture borders remain uncoloured around pictures that are not in matching positions. Players are free to move correctly placed pictures throughout the activity.

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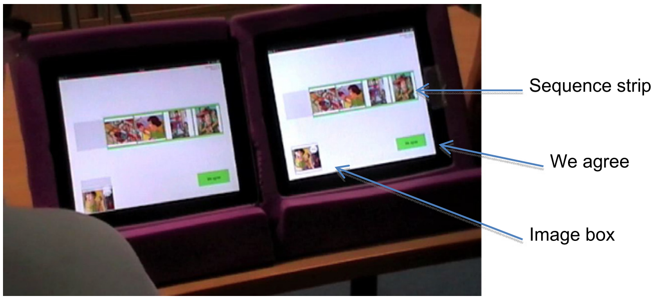

Fig. 4. The picture-sequencing task on dual tablets. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table 1
Experimental procedure.

Tablet	Practice round Adult–Child	First round Adult–Child	Second round Peer–Peer
Session 1			
Single	Child 1 Child 2	Child 1 Child 2	Child 1 + Child 2
Dual	Child 3 Child 4	Child 3 Child 4	Child 3 + Child 4
Single	Child 5 Child 6	Child 5 Child 6	Child 5 + Child 6
Dual	Child 7 Child 8	Child 7 Child 8	Child 7 + Child 8
Session 2			
Dual	Child 1 Child 2	Child 1 Child 2	Child 1 + Child 2
Single	Child 3 Child 4	Child 3 Child 4	Child 3 + Child 4
Dual	Child 5 Child 6	Child 5 Child 6	Child 5 + Child 6
Single	Child 7 Child 8	Child 7 Child 8	Child 7 + Child 8

3. Method

The experimental design was within-subjects with two independent variables: tablet configuration (single or dual, Fig. 2) and partner (adult or LDA peer). The dependent variables were: other-awareness (active other-awareness and attentional other-awareness), engagement (approach to task and withdrawal from task), imitation and communication.

3.1. Participants

Eight boys aged 5–12 years ($M = 9.2$ years, $SD = 3.3$ years) diagnosed with autism and a severe learning disability, attending one of three classes within the Autistic Spectrum Conditions Department of a special school in East Sussex, UK. Ethical approval was granted for the study and parental consent was given for the children to take part and to be videotaped. A key-worker was with children at all times to make sure they were happy to participate and the children were free to withdraw from the experiment at any time.

3.2. Procedure

The study was carried out in a separate room close to the children's classrooms with equipment set up as shown in Fig. 2. The class teachers' advice was used to place children into pairs. All participants had a practice round with an adult before testing began with each of the single and dual tablet conditions. The adult throughout the practice and testing rounds was the experimenter. Children completed the adult–child condition before the peer partner condition. This was to give the LDA children as much experience of the activity with adult support before they worked in peer partnerships. The order of the single and dual tablet conditions was counterbalanced, as shown in Table 1. A session for each pair took approximately 20 min and there was a week between the first and second sessions.

4. Behavioural coding

4.1. Other-awareness

Other-awareness, joint attention, imitation and communicative behaviour are all fundamental aspects of social interaction, and are impaired in autism. We developed a coding scheme. [42] to identify other-awareness behaviour displayed during a collaborative activity using two subcategories; *attentional* other-awareness and *active* other-awareness. LDA children's behaviour was coded for *attentional other-awareness*: behaviour that is judged to be related to a partner's e.g., pausing while interacting with an activity to watch a partner interact with the activity, as shown in Fig. 5 and *active other-awareness*: behaviour that is related to and contingent on a partner's actions e.g. a child places a picture on their sequence strip then watches a partner place the same picture on their corresponding strip and when game representations are identical, the child contingently presses 'We agree', as shown in Fig. 6. Table 2 gives detailed descriptions of the behaviours that were identified and judged to represent attentional (Fig. 5) and active (Fig. 6) other-awareness specific to the technology and activity used in this study.

Other-awareness, was coded by two experimenters, one naïve to the hypothesis, with a Kappa inter-rater reliability statistic on a random selection of 25% of the data of $k = 0.94$, considered to represent excellent agreement [46,47].

4.2. Imitation

We observed two forms of imitation in peer pairs: *follower imitation*, the imitation of a partner's action by a participant naïve to the objective of the activity, showing no understanding of their partner's intentions related to the task or discernible collaborative intent and *strategic imitation*, defined as intentional copying of a naïve peer partner as a means to progress through the activity, displaying both task understanding and collaborative intent. Follower and strategic imitation was coded by two experimenters, one naïve to the hypothesis, with a Kappa inter-rater reliability statistic on a random selection of 25% of the data of $k = 0.94$, considered to represent excellent agreement [46,47].

4.3. Engagement

LDA children's level of engagement with the activity was assessed using measures of approach to task and withdrawal from task, illustrated in Table 3. Video recordings were coded by two experimenters, one naïve to the hypothesis, with a Kappa inter-rater reliability statistic on a random selection of 25% of the data of $k = 0.80$, considered to represent excellent agreement [46,47].

5. Results

5.1. Analysis

The experimental design was repeated measures and peer–peer data is dependent, resulting in only four data sets. Hence,

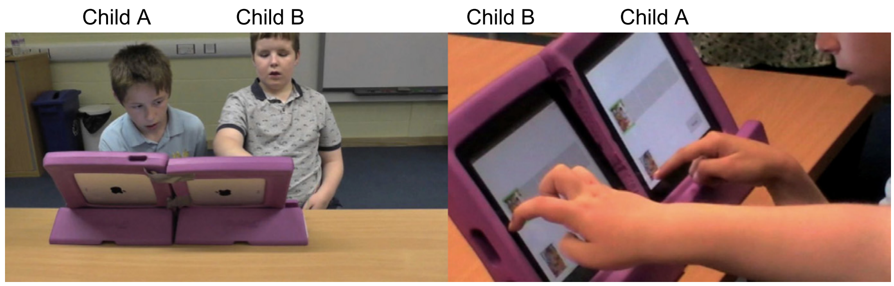

Fig. 5. Attentional other-awareness on dual tablets. The face view (left) demonstrates that child A is observing his partner and the screen view (right) shows that child A has paused his activity and child B is interacting with the activity.

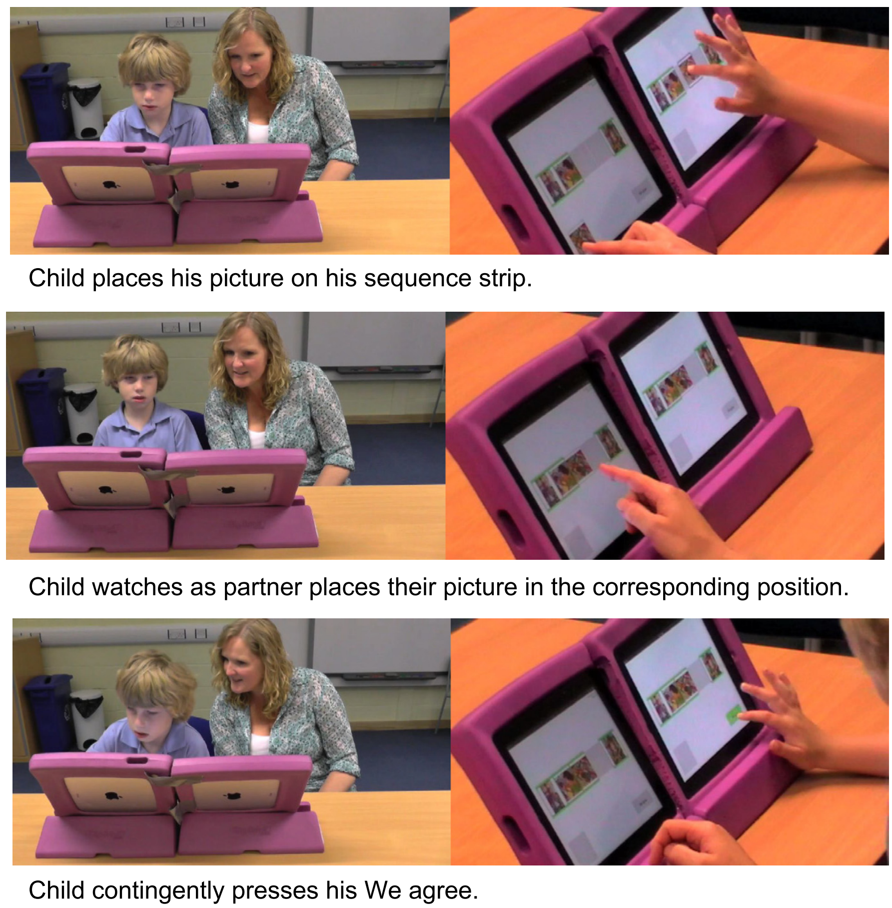

Fig. 6. Active other-awareness on dual tablets.

comparisons were made using non-parametric related samples Wilcoxon's signed-rank tests. However, the statistics must be considered with caution due to the increased chance of a Type 1 error when running repeated tests, and given that corrections for multiple comparisons are not robust at this sample size. Effect sizes are also reported; an r value of .3 is considered a medium effect and .5 a large effect size according to Cohen's criteria [48].

5.2. *Engagement*

We looked first at withdrawal, to assess whether or not LDA children remained involved with the activity. The mean frequency of withdrawal from task was low in all conditions (Fig. 7) and there were no differences in withdrawal behaviour in LDA children using single or dual tablets with a peer partner ($T = 6, z = -.95, p > .05$) or an adult partner, ($T = 1, z = -.45, p > .05$). Therefore, we can assume that children remained engaged with the activity in all conditions.

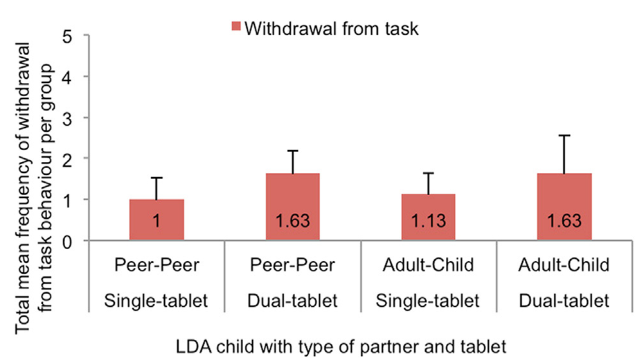

Fig. 7. Mean frequency and standard error of withdrawal from task behaviour displayed by LDA children partnered by an adult and peer using a single or dual tablet.

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Table 2
Tablet other-awareness coding scheme.

Active other-awareness	Attentional other-awareness
Waiting while looking at their partner's ***screen*** as partner is doing the task, then *pressing 'We agree'* ***before*** *partner*	Looking at their partner's ***screen*** as their partner does the task
Waiting while looking at ***partner*** as they do the task, then *pressing 'We agree'* ***before*** *partner*	Looking at ***partne****r* as their partner does the task
Looking from partner to screen ***contingent on*** continuing own task	Looking from ***partner*** /**screen** to ***own screen***—visual checking
Moving already placed piece to match/copy their partner's arrangement without correction being given, but after looking at partner's side	Clicking 'we agree' or moving piece after looking at **partner/partner's screen** but not contingent on partner's action
Actively preventing partner from interacting with the game	
Imitating verbally game related comments	
Trying to move partner's game pieces	
Telling & or pointing to inform partner about the game	
Responding appropriately to information given by partner	
Asking/indicating for partner's help	
Responding appropriately to request for help by partner	
Watching partner make a move and clearly copying action	
Engaging in turn-taking—indicated verbally or behaviourally	

Table 3
Tablet engagement coding scheme.

Approach to task	Withdrawal from task
Smiling/laughing related to task	Moving/looking away from task (not distracted by another activity/person/noise unrelated to game)
Clicking we agree to start game	Giving up due to an inability to move pieces
Randomly clicking We agree moving piece around	Playing about with technology instead of with task
Randomly moving game pieces around interface without reference to partner' game	Angry, frustrated or distressed behaviour
Moving piece when told to by experimenter	

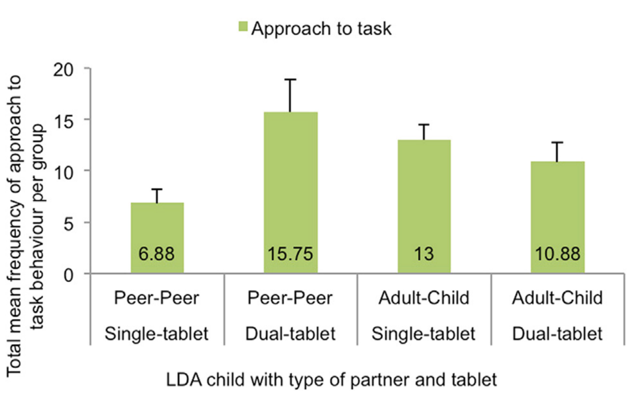

Fig. 8. Mean frequency and standard error of approach to task behaviour displayed by LDA children partnered by an adult and peer using a single or dual tablet.

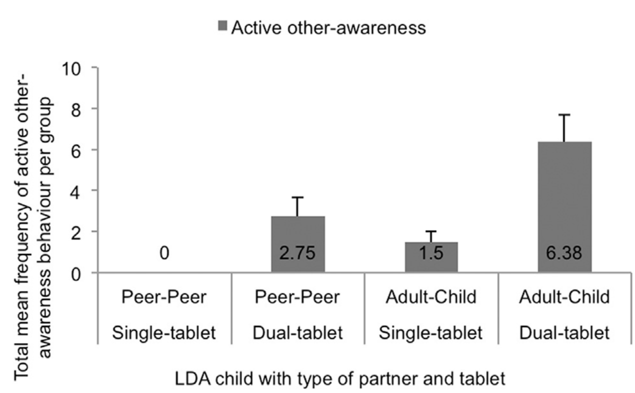

Fig. 9. Mean frequency and standard error of active other-awareness behaviour produced by LDA children partnered by a peer or adult using a single or dual tablet.

Figures for approach show a different picture. Fig. 8 shows that the mean frequency of peer–peer approach with a single tablet is around half that of the other conditions. LDA children partnered by a peer displayed significantly more approach to task using a dual tablet compared to a single tablet ($T = 1, z = -2.38, p < .05, r = -.42$), and also significantly more approach behaviour using a single tablet partnered by an adult than partnered by a peer ($T = 1.50, z = -2.31, p < .05, r = .41$). In contrast, there were no significant differences found in approach to task for single and dual tablets when an LDA child was partnered by an adult ($T = 6, z = -1.36, p > .05$). Notably, peer partnerships using the dual tablets generated the highest mean frequency of approach to task behaviour and the lowest sharing a single tablet.

5.3. Active other-awareness

Peer partnerships in the single tablet condition produced no active other-awareness of partner, unlike the dual tablet condition, as shown in Fig. 9, ($T = 0, z = -2.03, p < .05, r = -.36$). Active other-awareness was absent in the peer single tablet condition, but it was evident in this single tablet condition with an adult. With dual tablets and an adult partner, LDA children displayed significantly more active other-awareness compared to an adult-paired single tablet ($T = 1, z = -2.39, p < .05, r = -.42$).

Overall there was no effect of partner on active other-awareness for dual tablets, ($T = 6, z = -1.69, p = .09$). However, LDA children were significantly more actively aware of an adult partner compared to a peer partner using a single tablet ($T = 0, z = -2.03, p < .05, r = -0.37$).

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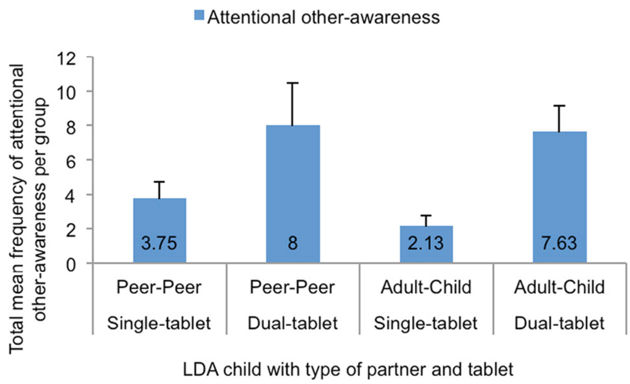

Fig. 10. Mean frequency and standard error of attentional other-awareness behaviour produced by LDA children partnered by a peer or adult using a single or dual tablet.

5.4. Attentional other-awareness

Results for attentional other-awareness, in Fig. 10 show that children in peer partnerships were also more attentionally aware of their partner using the dual tablets compared to a single tablet ($T = 0, z = -2.03, p < .05, r = -0.36$), as were children partnered by an adult ($T = 2, z = -2.25, p < .05, r = -.41$). Overall there was no effect of partner on attentional other-awareness for dual tablets ($T = 17.50, z = -.07, p = .94$) or for a single tablet ($T = 6.50, z = -1.27, p = .20$).

6. Further analysis of other-awareness behaviour

The other-awareness behaviour generated by LDA children in the four conditions is described below in fine detail using the frequency of the subtypes of behaviour that make up the active and attentional other-awareness coding scheme.

6.1. Peer–peer using single tablet

LDA children were not able to coordinate their behaviour in order to perform the activity with a single tablet. In general one child would begin the activity and the experimenter would need to encourage the other child to participate, as the active peer would not invite his partner to take part. Peer partners sharing the single tablet displayed attentional, but not active, other-awareness, the vast majority of which was looking at the tablet *screen* while their partner did the activity (26/30). The remaining four attentional other-awareness behaviours involved looking at the *partner* while he did task.

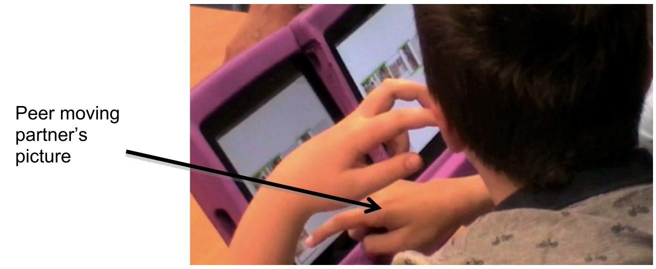

Fig. 12. The image shows a pair of LDA peers using dual tablets. The child in the picture has just interacted with his screen, but his picture remains in the image box, so his partner leans across to place his partner's picture on the sequence strip. Therefore, placing both pictures in corresponding positions on their respective strips, so that pressing the 'We agree' icons will generate another picture.

6.2. Adult–child using single tablet

LDA children displayed a greater variety of other-awareness behaviour with an adult partner using a single tablet compared to a peer partner. Active other-awareness was low in frequency, but apparent, and consisted of follower imitation (1/12 active other-awareness behaviours) and verbal imitation (3/12) and some communicative behaviour. Communicative behaviour comprised of responding appropriately to information given by the experimenter (3/12) and pointing to inform partner about the game (2/12). Interestingly, one child actively prevented the adult partner from interacting with the activity by pushing their hand away on two occasions. This behaviour was only seen in the adult–child single tablet condition.

6.3. Peer–peer using dual tablets

The dual tablet yielded a greater number of active other-awareness behaviours in peer partnerships, with over a quarter of the total other-awareness behaviour being active (22/86). Of the active behaviour, 41% were imitation, strategic (7/22) or follower imitation (2/22). Fig. 11 shows an example of follower imitation. Peers using the dual tablet were observed to interact with their partner's screen (illustrated in Fig. 12). This was surprising, as peers appeared reluctant to 'invade a peer's space' in order to interact with the shared screen using the single tablet. This type of active behaviour was quite frequent, making up 32% (7/22) of the active other-awareness behaviour in this condition. There was a very small, but important emergence of communicative behaviour (2/22), in this case, 'pointing to inform their partner about the game'. This was significant as the LDA children rarely communicated with each other during the tasks.

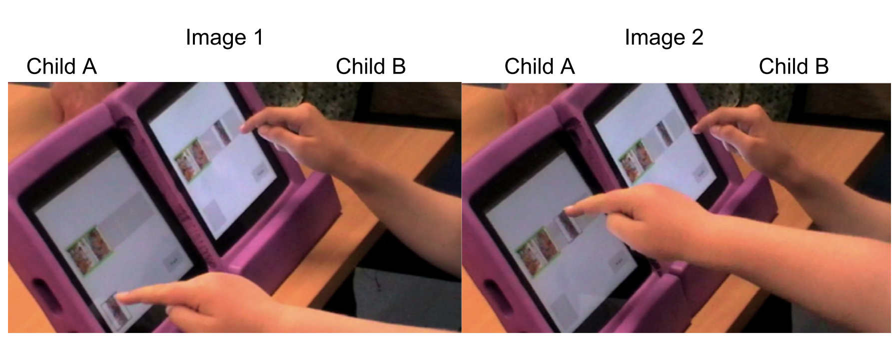

Fig. 11. In image 1, child A watches child B place his third picture on the strip and contingently places his picture onto the same slot on his sequence strip, shown in image 2, displaying follower imitation. The imitation is judged as follower as child B does not press his 'We agree' following the imitative action and therefore does not display an understanding of the requirement to match, but is using imitation to overcome his lack of understanding.

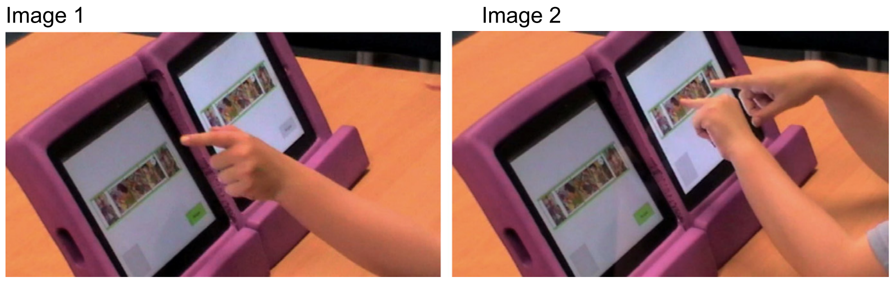

Fig. 13. Child–adult partners using dual tablets. All the pictures were on the sequencing strip and the child spontaneously gestured to the adult's screen (image 1) and then to two pictures on his screen (image 2), using the game representations to indicate (correctly) to the adult partner that the pictures were not in the correct sequence.

6.4. Adult–child using dual tablets

Of the 112 total other-awareness behaviours produced by children partnered by an adult using dual tablets, 45% (51) were active. Analysing these revealed that an adult partner was associated with more communicative behaviour, increasing from 2 instances using dual tablets with a peer partner to 16 instances with an adult partner. This accounted for 31% (16/51) of the active other-awareness behaviour produced by children with dual tablets partnered by an adult. The communicative behaviour consisted of two forms: 'Telling or pointing to inform partner about the game' (3/51) was observed in two of the LDA children and 'responding appropriately to information or a behavioural request' from the adult partner accounted for 15/51 of active other-awareness and was seen in four of the eight participants. Imitation represented 24% of active other-awareness, with strategic imitation accounting for 7/12 and follower imitation the remaining 5/12 instances. LDA children partnered by an adult using dual tablets also interacted with the adult partner's screen (7/51), although proportionally less frequently compared to peer partnerships using dual tablets.

6.5. Communicative behaviour

Communicative behaviour in the LDA children consisted of informing their partner about something related to the activity or responding to information given by the partner. In both instances the communicative behaviour could be either verbal or gestural. This often took the form of responses to questions about picture placement such as, "Where do you want to put it?" or "Where is mine?" with children pointing in response. A rare occurrence was a verbal response such as "yes" or imitating verbal comments about the picture sequence.

The LDA children in this study had limited verbal ability, but with dual tablets a participant did use gesture to share information with his peer and with an adult partner (Fig. 13). An adult partner with dual tablets was able to scaffold communicative behaviour by using the reference of the joint activity to initiate responses to information, and this form of communicative scaffolding achieved a response from half the LDA children in this study. Most notable was the attempt by one child to use approximations of words accompanied with gestures to indicate the need to re-order the picture sequence, so that the pictures would be in the correct sequence (Fig. 13). This was obviously effortful for him, and his speech was unclear, but by using his own and his adult partner's pictures as a shared reference point he was able to communicate his idea clearly. This was surprising, as the pictures did not have to be in the correct order to complete the task and the child instigated an opening for further dialogue between himself and his adult partner. The same child also made two gestural attempts to communicate with his peer partner in the dual tablet condition by pointing to his partner's 'We agree' icon and image box to encourage his partner to interact with the activity. However, using the single tablet he completed the task paying little notice to his adult partner and making no such communicative attempts.

7. Discussion

The main finding of this study is that LDA children, with the support of dual tablets incorporating collaborative SCoSS software, were observed to successfully participate in a collaborative activity with a peer, generating significantly more active other-awareness behaviour than when sharing a single tablet. In comparison, LDA peer partners sharing a single tablet were unable to coordinate their behaviour to work collaboratively and active other-awareness was absent. The order of the single and dual tablets was counter-balanced: LDA children who experienced the dual tablet condition before the single tablet condition were found to display active other-awareness of a peer partner, but did not demonstrate this awareness in the subsequent single tablet condition. Therefore, in peer partnerships the dual tablet configuration was required to enable joint activity in LDA children and is in line with the findings of Holt and Yuill [42] for a constrained dual-mouse set-up.

The dual tablets were shown to be particularly effective at facilitating active other-awareness in LDA children when partnered by an adult. The adult partner in this study facilitated many active other-awareness behaviours by directing the child's attention to the activity, asking task-related questions and commenting on the pictures, in an attempt to catch the LDA partner's interest. Responding to such calls for attention by adult partners is an early emerging skill in children with autism [49,50]. Nevertheless, LDA children in this study needed the support of the collaborative software and dual tablet technology to exhibit this kind of response. Carpenter et al. [49] assessed only interaction with an adult partner. The present study extends our knowledge of peer–peer interaction in LDA, showing that LDA children given appropriate collaborative support can use gesture to direct a peer partner's attention to a joint activity. Furthermore, this study shows that adult partners using a collaborative set-up can promote LDA children to use gesture for information-sharing, as well as corresponding appropriately to information from the adult partner. Our finding that using collaborative software to support other-awareness in LDA children can facilitate communicative behaviour is in line with research that demonstrates joint attention ability predicts language ability [22]. This relation also suggests that supporting joint attention online i.e., moment-to-moment during a joint activity, in children with autism may facilitate the emergence of communicative behaviour.

The levels of withdrawal from the task for each condition were low and similar for either type of partner, indicating that the children were not disengaged from the activity. However, LDA children showed significantly less approach behaviour when working with a peer using a single tablet than with dual tablets. This lower frequency of approach to task behaviour in the single tablet condition for peer partnerships may illustrate the challenge LDA children have in working with another LDA peer in class without appropriate support. It may also reflect an inability to initiate interaction with an activity, when this involves sharing a

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single tablet with a LDA peer. This proposal is supported by the fact that LDA children remained attentionally aware of their peer partner during the single tablet condition and with dual tablets they produced the highest mean frequency of approach to task behaviour.

Our findings demonstrate that dual tablets were of benefit in situations involving both types of partner; dual tablets used by adult–child partnerships were found to promote more communicative (verbal and gestural) and imitative behaviour and peer partnerships were found to support peer imitation. Joint attention and imitation are associated with language development in children with autism [22–25,19]. Therefore, it would be profitable to assess whether dual tablets used to promote imitation through joint activities have potential as an intervention to support language development in LDA children. Forms of imitative behaviour such as contingent object imitation [15] emerge before synchronic imitation [51,52] in typically developing children. We found that collaborative activities in LDA children require the use of a variety of imitative skills and that the type of partner has an effect on the frequency of imitation. Therefore adult and peer partners may offer complementary roles in supporting the development of imitation and collaboration through the collaborative process. We propose that when using computer technology to support joint activities and collaboration in LDA children, such an intervention needs to consider and take advantage of the different strengths of adult and peer partnerships.

The comparative technology design we used shows that it is not enough just to offer technology to LDA children if the aim is to support social interaction. When LDA peers worked together sharing a single tablet they were not observed to produce any form of contingent action, and were not actively aware of their partner. Therefore, technology alone is not sufficient to facilitate collaborative activity in LDA children: it is the design of the affordances offered by the technology that is critical. In this case there are a number of affordances that we believe contributed to the overall efficacy of the technological intervention. Firstly, the LDA children were given a tablet each and we believe this allows for autonomous interaction with the technology. The children were unable or unwilling to share a single tablet. Secondly, each tablet has an identical representation of the picture sequencing activity. This enables each child's actions to be represented explicitly, for both players to observe. Thirdly, feedback is given by the technology on correct picture placement and fourthly, this feedback is constrained such that only pictures placed in corresponding positions to the partner's placement allow task progress. We consider these are key affordances that give LDA children space to explore the picture sequencing problem, with feedback offered consistently and as frequently as required, allowing repeated attempts in an effort to understand the aim of the activity. The requirement to agree in matching picture placement with the partner is instrumental in supporting joint activity.

The findings of this study are clearly provisional, given the limitations of sample size and consequent limitations in power of statistical testing. Further research is clearly needed to assess the generalisability and scope of collaborative technology designs. During the study the adult partnering the LDA child was the experimenter and this decision was made to control for any potential differences in the interactive style of participant's teachers/keyworkers. It would be very beneficial, though, to include teachers/keyworkers as activity partners given their role in school settings: if this technology was offered as an intervention in schools it would be teachers/keyworkers that would be delivering it. A strength of this study is the fact that the materials used to create the picture sequencing activities were selected so as to be of interest to the LDA children and that their engagement with the task was evaluated. However, we have not investigated if some materials are more effective at engaging LDA children than others and this is an area that warrants further investigation. It would also be useful to examine whether some forms of activities, such as picture sequencing, supports different or similar social interactive behaviour compared to picture sorting. The study reported here examined the difference in LDA children's behaviour when supported by a dual or single tablet configuration with different partners and demonstrates that a dual tablet is more effective at facilitating other-awareness and communication. We recommend that future research should assess any potential long-term benefits that frequent exposure to collaborative activities might have on the social interaction skills of LDA children.

This paper demonstrates that it is possible to design technology to address a specific form of interaction in LDA children, in this case other-awareness and communication through a collaborative activity. It supports the benefit of integrating the 3T [8] design approach of theory, technology and thoughts during the design process and in particular how exploiting the collaborative framework put forward by Yuill and Rogers [9] can support design for collaboration. Additionally, this paper suggests how the evaluation process of a prototype technological intervention might be used both to validate its efficacy as an intervention targeting a specific impairment, and as a method to incorporate the views and reactions of less verbal LDA children.

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