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Digital media and children with Autism Spectrum Disorder:

Media usage, parental concerns, and the potential for digital clinical screening

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Abstract

In Germany, there are long waiting times for the diagnostic procedure of autism spectrum disorder (ASD), which creates uncertainty for the entire family and delays the start of family support and child therapy. This highlights the need for improved care for suspected cases of ASD. Digital technologies have the potential to support the screening and diagnostic processes for ASD. Therefore, this doctoral dissertation investigates the overarching research question: *Can the digital screening tool, which has been developed by the IDEAS consortium, contribute to the detection of boys with ASD?* Studies have often assumed that children with ASD are attracted to digital media, but this has not been investigated systematically. Accordingly, the media use of children with and without ASD was examined both in Study I and subsequently in Study II using a parent questionnaire. Study I included $n = 15$ parents of boys with ASD and $n = 78$ parents of typically developing (TD) boys. Study II included $n = 117$ parents of children with ASD and $n = 58$ parents of TD children. All children were between 6 and 11 years old. Mann-Whitney *U*-tests and Spearman correlations were used for the analyses. These studies indicate that children with ASD are familiar with and capable of using digital media, suggesting they are likely to accept and engage with digital screening tools. Study II also investigated parents' concerns about their children's media use, particularly regarding ASD symptoms. This investigation also included hierarchical regression models. In terms of developing a digital screening tool, it is essential that ASD symptoms can be observed in a digital setting. Study II indicates that parents were not concerned that their child's ASD symptoms would intensify. These results highlight the importance of examining whether ASD symptoms occur in a digital setting. Experimental Study III investigated the media equation of interaction between $N = 20$ boys with ASD, aged 6 to 11, using an equivalence test in a within-subject design. Study III indicates that children with ASD behave similarly in digital and real-life settings. This suggests that ASD symptoms can be detected in digital settings. Finally, Study IV examined whether digital screening tasks (emotion recognition and visual preference) could differentiate between children with and without ASD. The study included $n = 24$ boys with ASD and $n = 24$ TD boys, all between the ages of 6 and 11. Mixed logistic models were used

for the emotion recognition task, mixed linear models for the visual preference task, and decision trees using the Gini index. Both the emotion recognition and visual preference tasks have an accuracy rate of 81.25%, and they should be considered together when making decisions. Overall, the results demonstrate that boys with ASD accept and are able to use a digital screening tool, that symptoms of ASD can be elicited in a digital setting, and that the tool can distinguish between boys with and without ASD. Therefore, the digital screening tool can contribute to the detection of boys with ASD. However, further optimization is needed to improve the early detection of ASD.

List of publications for the dissertation

Four studies are relevant to this cumulative doctoral dissertation, titled: *Digital media and children with Autism Spectrum Disorder: Media usage, parental concerns, and the potential for digital clinical screening*. All four studies have been published in different peer-reviewed international journals.

Study I (Appendix A)**:** **Pliska, L.**, Neitzel, I., & Ritterfeld, U. (2023b). Toward digital participation in individuals with Autism Spectrum Disorder. *Frontiers in Communication, 8*(1224585). https://doi.org/10.3389/fcomm.2023.1224585

Study II (Appendix B)**:** **Pliska, L.**, Kunina-Habenicht, O., & Ritterfeld, U. (2025a). Media use among children with ASD: Perspectives and concerns of parents. *PLOS One, 20*(10), e0332504. https://doi.org/10.1371/journal.pone.0332504

Study III (Appendix C)**:** **Pliska, L.**, Neitzel, I., & Ritterfeld, U. (2025b). Media Equation of the Interaction of Children with Autism Spectrum Disorder: A Proof-of-Concept Approach Using an Equivalence Test in a Within-Subject Design. *Journal of Autism and Developmental Disorders.* https://doi.org/10.1007/s10803-025-06943-4

Study IV (Appendix D)**:** **Pliska, L.**, Neitzel, I., Buschermöhle, M., Kunina-Habenicht, O., & Ritterfeld, U. (2026). Digital screening of children with ASD: Diagnostic accuracy of emotion recognition and visual preference tasks. *BMC Psychiatry, 26*(75). https://doi.org/10.1186/s12888-025-07725-z

1 Introduction

Autism spectrum disorder (ASD) is a neurodevelopmental disorder that is classified by persistent deficits in social interaction and communication, as well as repetitive, restricted, and stereotyped patterns of interests, behavior, or activities over the lifespan (Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition [DSM-5]; American Psychiatric Association, 2013). The clinical presentation of ASD is heterogeneous, with multifaceted symptoms that vary widely between individuals (American Psychiatric Association, 2013; Wawer & Chojnicka, 2022). The incidence of ASD diagnoses has increased on a global scale (Bougeard et al., 2021; Chiarotti & Venerosi, 2020; Zeidan et al., 2022), with approximately 1 in 100 children receiving a diagnosis of ASD (Zeidan et al., 2022). Diagnosing ASD using gold standard methods (best validated instruments), such as the Autism Diagnostic Observation Schedule, Second Edition (ADOS-2; Lord et al., 2012) and Autism Diagnostic Interview – Revised (ADI-R; Lord et al., 1994), usually takes several hours (Tariq et al., 2018) and requires extensive clinical expertise and training (Kamp-Becker et al., 2021). This leads to limited personnel capacity (Kamp-Becker et al., 2021) and, consequently, long waiting times for an ASD diagnosis (Kamp-Becker et al., 2021; Tariq et al., 2018). For example, a meta-analysis by Höfer et al. (2019) in Germany displayed that most parents already had the first suspicion when their child was two years old, but the average age of diagnosis is 78.5 months (6;6 years [years;months]). Thus, the average age of diagnosis in Germany is notably higher than the average age derived from a meta-analysis of over 35 countries, which was found to be 60.48 months (5;0 years; van't Hof et al., 2021). Especially, children without intellectual impairments are diagnosed over a year later than children with intellectual impairments (Höfer et al., 2019). This long waiting time creates uncertainty for the whole family (Wiggins et al., 2006) and delays the start of family support and child therapy (Tariq et al., 2018). These delays can have incremental effects, as it has been proven that an early start to intervention results in better developmental outcomes (Lin et al., 2022; Wiggins et al., 2006). Taken together, the current situation highlights the need for improved forms of care for suspected cases of ASD in Germany (Höfer et al., 2019).

Against the backdrop of digitalization, an increasing number of applications (apps) are being developed for digital screening of children with ASD, such as the early autism screening tool (EAST; Arshad et al., 2020) and ASDetect (Barbaro & Yaari, 2020). The project 'Identification of Autism Spectrum Disorder using speech and facial expression recognition' (IDEAS; 2022-2025; funding code: 13GW0584A-E [all project partners], 13GW0584D [TUDO]) aims to develop a digital screening tool for ASD that considers the three typical symptom categories: language, facial expression, and interaction (for an overview of the project, see Kachel et al., 2025). It is a (grand-)funded project by the German Federal Ministry of Research, Technology and Space (BMFTR; formerly the German Federal Ministry of Education and Research, BMBF), and focuses on improving care for individuals suspected of having ASD. In the future, the screening tool should be suitable for both boys and girls with ASD. However, it is assumed that the symptoms of ASD present differently in girls than in boys (cf. Hodges et al., 2020; Hull et al., 2020). It is currently questionable whether a single tool can identify both boys and girls with ASD. Additionally, ASD is more prevalent in boys than in girls (Elsabbagh et al., 2012; Jiménez-Muñoz et al., 2022; Zeidan et al., 2022), with a male-to-female ratio of 3:1 (Loomes et al., 2017). As a first step towards developing a digital screening tool for children with ASD (boys and girls), the target group was selected to be boys. Furthermore, the age range for boys was set at 6 to 11 years. The initial tests to evaluate the digital screening tool require a comparison between children with ASD confirmed by a diagnosis and typically developing (TD) children. This is necessary to determine whether the screening can differentiate between the two groups (ASD vs. TD). Since the average age of diagnosis in Germany is 6;6 years (Höfer et al., 2019), the starting age of six years was chosen. Another reason for this starting age is that children in Germany start school between the ages of six and seven (see Fertig & Kluve, 2005). Overall, transitions such as starting and changing schools are important milestones in childhood (Andresen, 2020). As children in Germany usually attend primary school for four years before moving on to secondary school (Helbig & Nikolai, 2024), the upper age limit has been set at 11 years old.

The IDEAS project involves developing and testing software for identifying ASD using facial expressions, gestures, and language for digital screening purposes. Therefore, this tool should help reduce the number of children on the waiting list who are no longer suspected of having ASD after screening. However, there is one crucial question that has not been addressed yet, but is a necessary prerequisite for the implementation of the project: *Can the digital screening tool, which has been developed by the IDEAS consortium, contribute to the detection of boys with ASD?*

Technologies[1] such as digital media have been successfully used for educational and clinical purposes, such as diagnosis and intervention, for children with ASD (overview in Pliska et al., 2023b). Given the long waiting times for an ASD diagnosis, parents may perceive digital screening as useful for providing an initial assessment of their suspicions. According to the Technology Acceptance Model (Davis, 1986), perceived usefulness is the primary determinant of user acceptance (Davis & Granić, 2024). Therefore, it can be concluded that parents might accept and use a digital screening tool for their children with suspected ASD. However, children with ASD must be able and willing to use a digital screening tool. Therefore, it is essential that they are familiar with digital media and do not reject it. User acceptance is a prerequisite for the effectiveness of technology (Sprenger & Schwaninger, 2021). In the context of a digital screening tool, effectiveness means reliably identifying children with ASD. This enables parents to make informed decisions about subsequent steps. Studies on digital media often assume that children with ASD are attracted to it (e.g., Laurie et al., 2019; Mazurek & Engelhardt, 2013; Scholle et al., 2020). However, the studies consistently avoid evaluating this assumption, which may be based solely on the observation that children with ASD avoid social situations and the idea that they can compensate for this in digital environments. Since research on the media use of children with ASD is relatively new, studies on this topic are sparse (see Stiller & Mößle, 2018). Therefore, Study I (Pliska et al., 2023b; see Chapter 2)

[1] The term 'technology' is used generically as a superordinate (cf. Carroll, 2017). It encompasses digital media, including digital devices. Examples of digital devices are smartphones and tablets (screen-based media).

examined the media use of boys with ASD via a questionnaire. This study investigates the extent to which media use differs between boys with and without ASD. The aim is to determine whether boys with ASD are familiar with and accept digital media.

Children's media use may be related to parental concerns (see Study I). Parents' concerns can be especially exacerbated if their child has been diagnosed with ASD (Laurie et al., 2019). Findings by MacMullin et al. (2016) show that parents of children with ASD are more likely to report that media use had an impact on their children's behavior in a negative way than parents of TD children. This is especially important when considering the concept of *virtual autism* (Zamfir, 2018), which refers to ASD-like symptoms caused by excessive screen time (Detroja & Bhatia, 2024). Therefore, Study II (Pliska et al., 2025a; see Chapter 3) examined parents' concerns regarding their child's media use and the exacerbation of ASD symptoms via an extensive online questionnaire. The study investigated whether parents' concerns about their children's media use differ between those with and without ASD, especially regarding exacerbating ASD symptoms.

In contrast to the concept of *virtual autism* (Zamfir, 2018), studies have shown that digital media can fulfill the need for sensory stimulation and solitary activity (Lane & Radesky, 2019; Mayer et al., 2024), help children with ASD to relax (Dumaru et al., 2024), and enable them to regulate themselves (Coyne et al., 2021; Gordon-Hacker & Gueron-Sela, 2020). Therefore, it is unclear to what extent ASD symptoms occur in digital settings. However, since the digital screening tool is intended to detect children with ASD, symptoms of ASD must be observed in a digital setting to distinguish between children with and without ASD. Therefore, it is necessary that ASD symptoms occur not only in a face-to-face situation but equally in a digital setting. The media equation has not yet been investigated in this regard, so Experimental Study III (Pliska et al., 2025b; see Chapter 4) addresses this issue. Study III examined whether boys with ASD behave in the same way in digital environments as they do during face-to-face interactions.

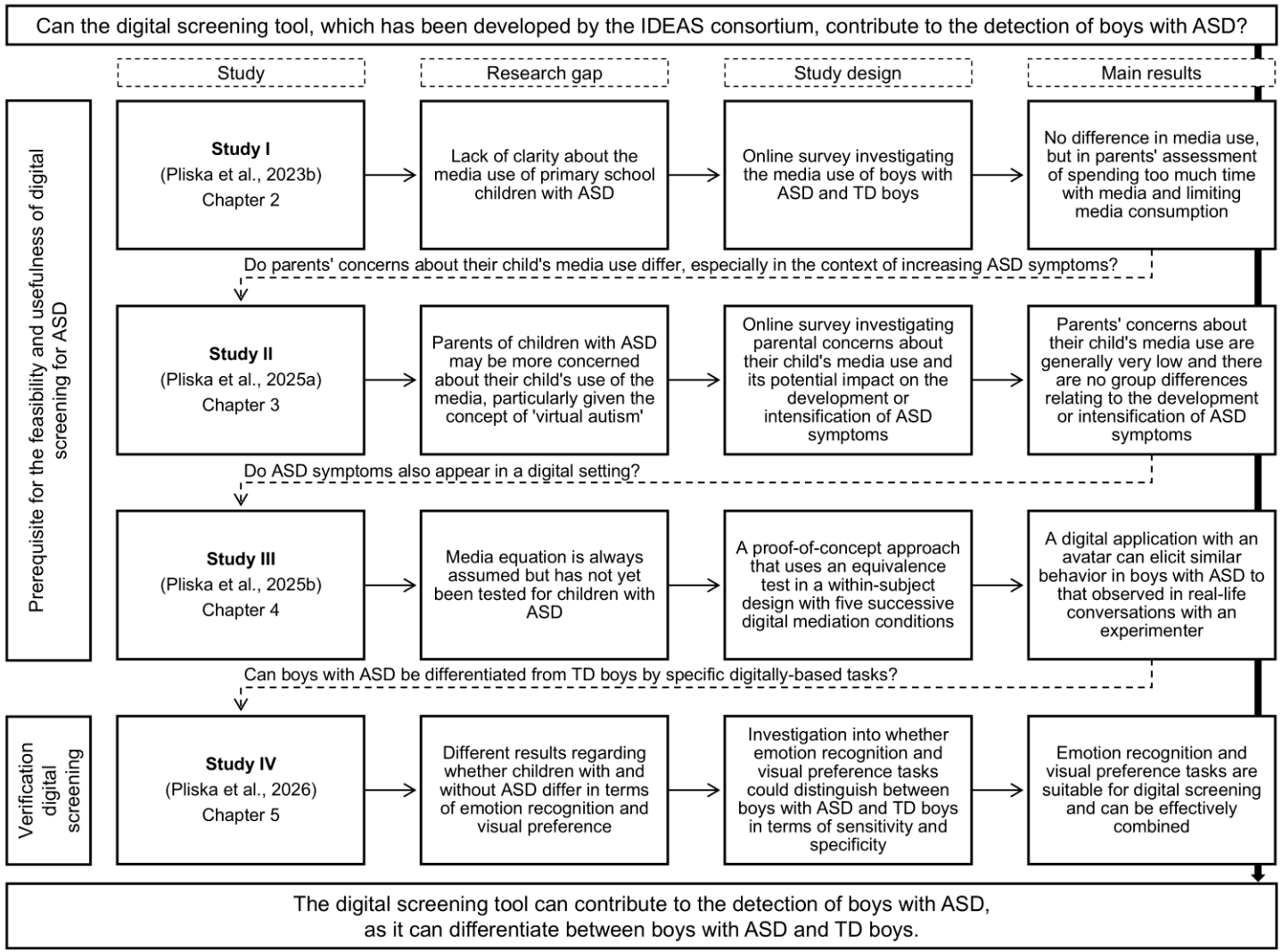
Since the goal of a digital screening tool is to distinguish between children with and without ASD, it must be examined whether the selected task of the tool can also make this

distinction. Tasks that could be used to investigate the prognostic ability of a digital screening tool for ASD could include emotion recognition and visual preference. Meta-analyses of individuals with ASD reported difficulties in emotion recognition (Uljarevic & Hamilton, 2013), as well as a preference for non-social stimuli over social stimuli (Chita-Tegmark, 2016). Therefore, Study IV (Pliska et al., 2026; see Chapter 5) investigated whether emotion recognition and visual preference tasks in a digital setting could distinguish between boys with ASD and TD boys. Following this approach, the accuracy regarding this distinction, as well as sensitivity and specificity, were calculated in Study IV.

This doctoral dissertation presents four systematic, successive studies that address the initial question: *Can the digital screening tool, which has been developed by the IDEAS consortium, contribute to the detection of boys with ASD?* Figure 1 provides a systematic overview of the doctoral dissertation project. The four studies of the doctoral dissertation are presented in Chapters 2 to 5. Since this doctoral dissertation is linked to the IDEAS project, each chapter begins with an introduction and explanation of its relevance to the project, as well as a delimitation. Finally, Chapter 6 provides a general discussion, in which the initial question is answered based on the four studies relevant to the doctoral dissertation (Chapter 6.1). Additionally, limitations and derivation of research desiderata (Chapter 6.2), as well as implications for clinical and therapeutic practice (Chapter 6.3), are outlined. Chapter 7 concludes the doctoral dissertation by determining whether the digital screening tool can contribute to the detection of boys with ASD and the social and clinical benefits.

Figure 1

Systematic overview of the sequential approach to addressing the research question in the doctoral dissertation



Note. The dashed arrows represent the connecting aspects of the studies.

2 Digital media usage among children with ASD

The IDEAS project is based on the assumption that children with ASD are familiar with using digital media. However, research into the use of digital media by children with ASD is restricted (see Stiller & Mößle, 2018). It is important to get a better understanding of media usage in children with ASD. A digital screening might not be useful if children with ASD cannot handle or reject digital devices. Alternatively, children must participate in an intervention to become familiar with digital devices and learn how to use them before a digital screening is conducted. Therefore, the aim of Study I (*Media use*; see Appendix A) is to improve the necessary understanding of media usage in children with ASD.

Study I

Pliska, L., Neitzel, I., & Ritterfeld, U. (2023b). Toward digital participation in individuals with Autism Spectrum Disorder. *Frontiers in Communication, 8*(1224585). https://doi.org/10.3389/fcomm.2023.1224585

Introduction

The use of new technologies, such as eye tracking and virtual reality, for clinical diagnosis and intervention, as well as for educational purposes, has been discussed and investigated with children with ASD (see Introduction in Pliska et al., 2023b). Although it has been consistently reported that children with ASD are attracted to digital technologies (Laurie et al., 2019; Mazurek & Engelhardt, 2013; Scholle et al., 2020), authors have consistently refrained from evaluating this assumption. The use of media and ASD is a relatively new topic in general, with most of the reviewed studies having been conducted in North America (Stiller & Mößle, 2018). This highlights a research gap for several European countries, including Germany (see Stiller & Mößle, 2018). Therefore, the present study aimed to shed light on media use among individuals with ASD, compared to TD children, in Germany. To this end, the following research question has been posed: How does the media use of boys with ASD aged 6 to 11 differ from the media use of TD boys in Germany?

Method

A total of n = 15 parents of boys aged 6 to 11 (M = 8.93 years, SD = 1.79) diagnosed with ASD in Germany completed a paper-and-pencil questionnaire regarding their children's media usage. For comparison, n = 78 parents of TD boys aged 6 to 11 (M = 8.21 years, SD = 1.57) filled out the same questionnaire online. None of the parents reported that their child had an intellectual disability. The questionnaire assessed media availability at home, frequency of use (never = 0, sometimes = 1, often = 2), reasons for using digital media as well as parents' perception of their child's confidence, enjoyment, and immersion (i.e., sense of non-mediation or *being there* while being involved with new media; Biocca, 2002) in digital media. Parents were also asked if they believed their child spent too much time on digital media and if they found it challenging to limit usage (10-point Likert scale). Mann-Whitney U-tests were employed for group comparisons related to media availability, reasons for use, and parental perceptions. Frequency of responses and percentages were calculated by dividing total responses by the number of respondents. Spearman correlations were conducted to explore relationships between Likert scale items. Additionally, manual two-to-one matching was performed based on parents' age and education level to address the higher education level of TD parents. Further comparisons were then made using Mann-Whitney U-tests. Significance was determined approximately for datasets with over 50 participants and exact significance for smaller samples.

Results and Discussion

The findings reveal that over 86% of participating families had access to at least five types of digital media at home, with no significant difference in the number of digital media and exposure between children with ASD and TD children (p > .05). This demonstrates the increasing presence of digital media in society (e.g., Spina et al., 2021) and its omnipresence in the lives of children, regardless of whether they have ASD. Additionally, the results regarding exposure contradict those of Dong et al. (2021) and Krishnan et al. (2021), who found that children with ASD spend more time using digital media than TD children. Ratings by parents of their child's confidence and enjoyment when using digital media, as well as their level of

immersion and belief that their child spends too much time on digital media, revealed no group differences (p > .05). Nevertheless, ratings were higher among the ASD group. However, parents' perceptions of the difficulties they had in limiting their children's media use showed a significant group difference (U = 285, z = -3.20, p = .001), with a moderate effect size (r = 0.33). Parents of children with ASD (M = 4.93, SD = 2.81) reported greater difficulty in limiting media use than parents of TD children (M = 2.57, SD = 2.11). Parents' assessment of whether their child spends too much time using digital media may depend on how severely they limit their child's media use. Parents who restrict their children's media use may be particularly concerned about their digital media consumption. This could be supported by the correlation between believing that their child spends too much time with digital media and having difficulty limiting their use of it (r_s = 0.51, p < .001, d = 1.19). Therefore, further research is needed to investigate parents' concerns about their children's media use. Overall, this study showed no differences in media use of children with and without ASD. However, it can support the assumption that children with ASD are attracted to digital media and use it frequently.

3 Parental concerns about media usage among children with ASD

Based on Study I (*Media use*), it can be assumed that children with ASD are familiar with and able to handle digital media. As emphasized at the beginning of Chapter 2, it is an essential prerequisite for the feasibility and usefulness of digital screening for ASD. However, Study I also highlighted that parental concerns could influence children's media use or vice versa. Therefore, it is important to investigate parental concerns about media usage among children with ASD. As some studies have shown an association between high media consumption and ASD-like symptoms (e.g., Al Moussawi et al., 2024; Aslan, 2024; Bibi et al., 2022; Detroja & Bhatia, 2024; Harlé, 2019), it is also necessary to consider parents' concerns about media use and ASD, respectively ASD-like symptoms. This is also relevant in the context of developing a digital screening tool for the IDEAS project. If parents of children with ASD are concerned that media consumption may exacerbate symptoms, this could suggest that ASD symptoms appear in digital settings, which are necessary for screening. Conversely, a lack of concern could suggest that children do not exhibit different behavior or fewer symptoms in

digital settings. The latter would be problematic for a digital screening. Therefore, the aim of Study II (*Parental concerns*; see Appendix B) is to investigate whether parents' concerns differ between children with and without ASD, and especially regarding media consumption and ASD(-like) symptoms.

Study II

Pliska, L., Kunina-Habenicht, O., & Ritterfeld, U. (2025a). Media use among children with ASD: Perspectives and concerns of parents. *PLOS One, 20*(10), e0332504. https://doi.org/10.1371/journal.pone.0332504

Introduction

Digital media has a significant impact on the daily lives of both adults and children. This raises concerns among parents about its effect on child development, particularly for those with ASD (e.g., Laurie et al., 2019). Parents' beliefs about media use influence how their children engage with digital media, including their perception of its benefits and the appropriate age for use (Benedetto & Ingrassia, 2021). For instance, parents may use media to help their child manage stress and difficult emotions (Coyne et al., 2021; Gordon-Hacker & Gueron-Sela, 2020). When a child is diagnosed with ASD, their parents' concerns may become exacerbated (Laurie et al., 2019). For example, parents of children with ASD highlight negative behavioral outcomes related to device use, particularly in terms of time demands and social consequences (Laurie et al., 2019; MacMullin et al., 2016). This led to the following research question: Do parents' attitudes and concerns differ between children with and without ASD? In this context, the concept of *virtual autism*, first introduced by Marius Zamfir (Zamfir, 2018), is worth mentioning. Zamfir (2018) hypothesized that excessive screen time can lead to ASD-like symptoms in very young children, a notion supported by various studies (Al Moussawi et al., 2024; Aslan, 2024; Bibi et al., 2022; Detroja & Bhatia, 2024; Harlé, 2019). Therefore, the question of whether parents' attitudes and concerns differ regarding media consumption and ASD(-like) symptoms is also addressed.

Method

An online survey to collect data on children's media usage and parents' attitudes and concerns about their children's media usage was completed by a total of n = 117 parents of children with ASD (n = 82 with comorbidities such as attention-deficit/hyperactivity disorder [ADHD]) and n = 58 parents of TD children aged 6 to 11 years. The survey examined the types of media available at home, the frequency and duration of children's media usage, and the reasons for using digital media. Parents were also asked to indicate the maximum amount of time their child should spend using digital media during the week and at weekends. For those who provided time ranges, means were calculated. Parents rated various statements about their child's media use in daily life and expressed their thoughts and concerns about it on a 10-point Likert scale. The study used group comparisons (Mann-Whitney U-test) and correlations (Spearman's correlation), both with Bonferroni correction, as well as hierarchical regressions.

Results and Discussion

This study found no significant difference in the frequency of digital media use of children with ASD and TD children (U = 2795.5, z = -1.82, $p\text{-}adj$ = 1), consistent with the findings of Study I (Pliska et al., 2023b). Key predictors of parental concerns included difficulties in limiting screen time, perceptions of their child's media preference and dependence, and coping ability without media. Unlike Laurie et al. (2019), this study did not find a correlation between parental assessment of the child's appropriate media time and parental concerns (r_s = 0.18, $p\text{-}adj$ = .372). Parents of children with ASD expressed greater concerns about media addiction (U = 4743.5, z = -4.29, $p\text{-}adj$ < .001, r = .7), supporting the findings of Yuan et al. (2024) that individuals with ASD are at a greater risk of screen addiction. Parents of children with ASD also expressed greater concerns about the negative effects of media use on their children's health and behavior (U = 3683.5, z = -3.19, $p\text{-}adj$ = .025, r = .65). This finding is consistent with the results reported by MacMullin et al. (2016). However, neither group expressed particularly high levels of concern. No differences were found between the groups regarding concerns about media use and the development or intensification of

ASD(-like) symptoms (U = 3348, z = -2.04, p-adj = .697), and concerns were generally low. This could indicate that media use does not exacerbate ASD symptoms. However, it would be valuable to investigate whether ASD symptoms are less pronounced or absent when engaging with digital media. For example, studies suggest that communication skills can be enhanced through digital media (Davchevska & Filipovski, 2024). Additionally, parents of children with ASD state that they give their child digital media more often to use when they are unwell, to help them self-regulate, than parents of TD children (U = 4571, z = -4.24, p-adj < .001, r = .69). This is consistent with the findings of Gordon-Hacker and Gueron-Sela (2020) and Coyne et al. (2021) and may be because screen media meet the sensory stimulation and solitary activity needs of children with ASD (Lane & Radesky, 2019; Mayer et al., 2024). Future research should investigate the potential positive effects of digital media on children with ASD, including whether media use might reduce ASD symptoms.

4 Media equation of the interaction of children with ASD

Study II (*Parental concerns*) supports Study I's (*Media use*) assumption that children with ASD are familiar with and prefer to use digital media, which is important for developing a digital screening tool. The results of Study II show that parents of children with ASD expressed greater concern about media use, particularly regarding its potential negative impact on health and behavior, than TD parents did. However, these concerns did not extend to child development or an intensification of ASD symptoms. For this reason, it could be assumed that parents of children with ASD have not perceived an intensification or any change in symptoms, which is necessary for digital screening. This is because ASD symptoms must be visible in a digital setting to be detected. However, it could also be that parents perceive fewer ASD symptoms in their children when using digital media. Study II does not provide evidence to make a statement about this. If this were the case, it would not be possible to screen for ASD digitally, because symptoms must be elicited and appear in a digital setting to distinguish between children with ASD and TD children. However, the media equation (i.e., technology-mediated experiences are perceived in the same way as non-mediated experiences; Lee, 2008; Reeves & Nass, 1996) is often simply assumed when developing digital screening tools

for children suspected of having ASD. This was also the case in the IDEAS project. First observational data of two boys with ASD in face-to-face versus digitally mediated situations by Pliska et al. (2023a) suggest similar behavior. Therefore, to improve the possibility of using digital screening, Study III (*Media equation*; see Appendix C) investigates whether children with ASD interact in the same way in a digital environment as they would in real life.

Study III

Pliska, L., Neitzel, I., & Ritterfeld, U. (2025b). Media Equation of the Interaction of Children with Autism Spectrum Disorder: A Proof-of-Concept Approach Using an Equivalence Test in a Within-Subject Design. *Journal of Autism and Developmental Disorders*. https://doi.org/10.1007/s10803-025-06943-4

Introduction

The detection of ASD can be significantly enhanced through digital technologies (Dahiya et al., 2021; Desideri et al., 2021; Kohli et al., 2022), which offer promising potential for early detection by utilizing objective data collection and analysis methods. Sensors in devices such as tablets can record a range of ASD-related symptoms in natural environments, including social-emotional and language skills (Mukherjee et al., 2024). Automated digital screening using avatars for interaction may be of particular interest to children with ASD (Georgescu et al., 2014), although the results are mixed (see Introduction in Pliska et al., 2025b). Overall, digital media and technology could be used to screen children with ASD. For digital screening of ASD to be effective, symptoms must be elicited and appear in a way that can distinguish between children with and without ASD. This requires similar behavior in digital situations as in real-life situations. The *rich-get-richer hypothesis* (Valkenburg & Peter, 2007) suggests continuity in social interactions across different settings, indicating that individuals with communication difficulties may also struggle with computer-mediated communication (Paulus et al., 2020). Although the media equation suggests that individuals behave in digital environments in the same way as they do in real life (Lee, 2008; Reeves & Nass, 1996), research involving children with ASD indicates a possible preference for digital interactions (Cardon & Azuma, 2012; MacMullin et al., 2016; Shane & Albert, 2008; van der Aa et al., 2016).

In this context, the extent to which avatars influence digital interactions among children with ASD is unclear. The following research question is examined to investigate the media equation of the interaction of children with ASD: Do children with ASD interact in a digital environment in the same way that they would interact in a face-to-face situation?

Method

A within-subjects design with five counterbalanced conditions representing a hierarchy of successive digital mediation was implemented: 1) face-to-face, 2) facetime, 3) avatar real-time, 4) video pre-recorded, and 5) avatar pre-recorded (see Chapter Research Design and Testing Materials in Pliska et al., 2025b). All five conditions were completed by n = 20 boys with ASD, aged 6 to 11 (M = 112.75 months, SD = 20.82, i.e., 9;4 years) without intellectual impairment. The analysis of a warm-up/conversation situation with three open-ended questions coded by two independent raters was conducted using an equivalence test. Therefore, the two-sided test (TOST; Lakens et al., 2018), which was adjusted to be based on the Wilcoxon signed-rank test with mu = 0.5 and a Bonferroni correction, was computed.

Results and Discussion

The results of the equivalence test indicate significant equivalence between face-to-face interactions and facetime (i.e., the real person and real-time conditions) in the first and second open-ended questions, as well as between facetime and the pre-recorded video condition (i.e., real person conditions) for the first open-ended question. These findings support the conclusions of Carter et al. (2014) that humans are more effective than avatars at eliciting communication, while contradicting the findings of Kellems et al. (2023) that children preferred avatars to humans. The third open-ended question showed significant equivalence between face-to-face interactions and real-time avatar interactions. Overall, children with ASD demonstrated similar interaction patterns across all five conditions, despite noted individual differences. Therefore, it can be assumed that a digital screening tool with an avatar can elicit similar behavior in children with ASD to that observed in real-life conversations with an experimenter. Thus, our study supports the *rich-get-richer hypothesis* (Valkenburg & Peter, 2007) by indicating continuity in social interactions across environments.

5 Diagnostic accuracy of emotion recognition and visual preference tasks

Study III (*Media equation*) shows that children with ASD exhibit similar behavior in a digital setting with an avatar as they do in a face-to-face setting with a human. Therefore, it can be assumed that ASD symptoms appear and are detectable during a digital screening. Thus, Study III demonstrated an essential prerequisite for developing a digital screening tool for detecting ASD. Subsequently, the next step is to evaluate whether specific digital-based tasks can distinguish between children with ASD and TD children. Study IV combines the IDEAS project and this doctoral dissertation, with the latter supporting the former. While the IDEAS project focuses on developing a digital screening tool based on language, facial expressions, and interactions, as well as verifying tasks in this context, this doctoral dissertation examined additional tasks for recognizing emotions and visual preferences. These additional tasks can be reviewed as part of the doctoral dissertation and then further developed and adapted for the final IDEAS application. The aim of Study IV (*Diagnostic accuracy*; see Appendix D) was to investigate whether an emotion recognition task and a visual preference task could distinguish between children with ASD and TD children in terms of sensitivity and specificity.

Study IV

Pliska, L., Neitzel, I., Buschermöhle, M., Kunina-Habenicht, O., & Ritterfeld, U. (2026). Digital screening of children with ASD: Diagnostic accuracy of emotion recognition and visual preference tasks. *BMC Psychiatry*, *26*(75). https://doi.org/10.1186/s12888-025-07725-z

Introduction

The screening and diagnostic processes for ASD could be enhanced by digital technologies (Desideri et al., 2021; Kohli et al., 2022), with clinical decisions being made more objectively and efficiently (Koehler & Falter-Wagner, 2023). One diagnostic criterion for ASD is emotional impairment, which includes deficits in recognizing emotions (Begeer et al., 2008). However, research has yielded contradictory findings regarding children's ability to identify basic emotions (see Chapter Emotion recognition in Pliska et al., 2026). Children with ASD may also struggle with emotional self-awareness (Huggins et al., 2021). This led to the first

question: 1) Can an emotion recognition task (comprising emotion recognition and situation description) be used to distinguish between children with and without ASD? Additionally, a reduced preference for social stimuli has been identified as a reliable way of distinguishing between ASD and TD groups (Mukherjee et al., 2024). This can be assessed using accessible technology, such as tablets, and eye-tracking methods (Mukherjee et al., 2024; Shic et al., 2022). Several studies have shown an atypical attention to social stimuli and a preference for non-social stimuli (see Chapter Visual Preference in Pliska et al., 2026). However, a study by Pliska et al. (2024) found no significant differences in visual preferences between boys with and without ASD. Overall, the findings of a study by Matyjek et al. (2024) suggest that the decisive factor is not whether children with ASD look at non-social stimuli more than TD children do. Instead, the difference may lie in the preference for social over non-social stimuli among TD children, while children with ASD may not show a preference. This led to the second question: 2) Can a visual preference task be used to distinguish between children with and without ASD?

Method

This study involved n = 24 boys with ASD (five boys with comorbid ADHD), as well as a matched control group of n = 24 TD boys (two boys with ADHD), all aged between 6 and 11 years. The tasks were displayed on a screen. The emotion recognition task involved five pictures of a girl displaying the five basic emotions (happiness, anger, sadness, disgust, and fear) taken from the Child Emotion Facial Expression Set by Negrão et al. (2021). Participants were shown each picture separately and were then asked to identify the emotion depicted, as well as a situation in which they had felt the same emotion. The visual preference task comprised six image pairs and four video pairs (the latter adopted from Polzer et al., 2022), with social and non-social stimuli presented on a screen for each pair. The image pairs featured people playing and cosmic scenes (galaxies and stars), while the video pairs featured a person displaying dynamic facial expressions and geometric shapes. Eye movements, including eye position and gaze direction, were recorded using a specifically developed iOS application (KIZMO Face-Analyzer) and analyzed using MATLAB. Mixed logistic models were applied to

the emotion recognition task, and mixed linear models to the visual preference task. Both tasks used decision trees based on the Gini index, which were then cross-tabulated with the predictions and compared with the actual group assignment.

Results and Discussion

In the context of comparing the ASD and TD groups in the emotion recognition task, the model prediction was only significant in terms of the recognition of the emotion 'fear' (OR = 15.41, 95%-CI: 1.72-138.14, p = .007), which children with ASD often recognized correctly. This finding aligns with the results reported by Evers et al. (2015). The model prediction failed to reach significance for recognizing the emotion 'sadness' (OR = 0.13, 95%-KI: 0.01-1.24, p = .098), but was significant for naming an example of this emotion (OR = 0.03, 95%-KI: 0.001-0.85, p = .034). Relevant to the decision tree were only recognizing the emotions 'fear' and 'sadness', with an accuracy of 81.25%, a sensitivity of 91.67% and a specificity of 70.83%. No significant differences were found between the ASD and TD groups in the visual preferences task (p > .05). This contradicts the results of studies by Kou et al. (2019) and Robain et al. (2022). Since a study by Matyjek et al. (2024) suggests that there is no difference in the relative duration of gaze fixation for social and non-social stimuli in ASD, but a difference in the TD group, the results of this study support this in the medium video (ASD: p > .05; TD: OR = 22.64, 95%-KI: 12.27-33.0, p < .001). There were no significant differences in the frequency of gaze changes between the two groups (p > .05). Gaze fixation on social videos and gaze changes in the video stimuli were relevant to the decision tree, achieving an accuracy of 81.25%, a sensitivity of 70.83%, and a specificity of 91.67%. As both tasks have an accuracy of 81.25% and reversed sensitivity and specificity, they are suitable for digital screening and can be effectively combined due to their complementary nature. It can therefore be concluded that digital technologies can be used to implement a screening tool comprising selected emotion recognition and visual preference tasks to differentiate between children with and without ASD.

6 General Discussion

The long waiting times for ASD diagnoses in Germany (Höfer et al., 2019), as well as the resulting delayed start of family support and child therapy (Tariq et al., 2018), highlight the need for improved forms of care for suspected cases of ASD (Höfer et al., 2019). The aim of the IDEAS project (2022-2025) is to create a digital screening tool that can distinguish between children with and without suspected ASD. There is still one important question that has not been answered. This is the overarching research question of this doctoral dissertation: *Can the digital screening tool, which has been developed by the IDEAS consortium, contribute to the detection of boys with ASD?* This question was examined in four successive studies (see Table 1 for a detailed overview of the four studies).

Study I (*Media use*), based on a questionnaire survey, demonstrated that there is no difference in media use between boys with and without ASD (see Chapter 2). The study also showed that both boys with and without ASD enjoy using digital media. Then, Study II (*Parental concerns*) revealed, through an online survey, that parents did not differ in their concerns about their children's media use (see Chapter 3). Additionally, concerns about exacerbated ASD symptoms due to media consumption are rare. Experimental Study III (*Media equation*) shows that boys with ASD behave the same way in a digital setting when interacting with an avatar as they do during face-to-face interactions with humans (see Chapter 4). Finally, Study IV (*Diagnostic accuracy*) demonstrated that emotion recognition and visual preference tasks can distinguish between boys with and without ASD (see Chapter 5). These tasks should be considered together when making decisions.

Studies I to IV of this doctoral dissertation are generally discussed regarding the overarching research question in Chapter 6.1. The limitations and derivation of research desiderata are shown in Chapter 6.2. Additionally, possible implications for clinical and therapeutic practice are demonstrated in Chapter 6.3.

Table 1

Detailed overview of the four studies of the dissertation project

Study	Titel	Research question	Data collection	Sample	Analyses	Main results	Journal
Study I: Pliska et al., 2023b (Appendix A)	Toward digital participation in individuals with Autism Spectrum Disorder	How does the media use of boys with ASD aged 6 to 11 differ from the media use of TD boys in Germany?	ASD: paper-and-pencil questionnaire TD: same questionnaire online	Parents of 15 boys with ASD aged 6-11 Parents of 78 TD boys aged 6-11	Mann-Whitney *U*-tests Spearman correlations	Media use does not differ between children with and without ASD Children enjoy using digital media	Frontiers in Communication (Impact Factor: 1.6)
Study II: Pliska et al., 2025a (Appendix B)	Media use among children with ASD: Perspectives and concerns of parents	Do parents' attitudes and concerns differ between children with and without ASD, especially regarding media consumption and ASD(-like) symptoms?	Online survey	Parents of 117 children with ASD aged 6-11 Parents of 58 TD children aged 6-11	Mann-Whitney *U*-test Spearman's correlation Hierarchical regressions	Parents' concerns are not different Concerns about the exacerbation of ASD symptoms due to media consumption are rare	PLOS One (Impact Factor: 2.6)
Study III: Pliska et al., 2025b (Appendix C)	Media Equation of the Interaction of Children with Autism Spectrum Disorder: A Proof-of-Concept Approach Using an Equivalence Test in a Within-Subject Design	Do children with ASD interact in a digital environment in the same way that they would interact in a face-to-face situation?	Experimental Study with five successive digital mediation conditions	20 boys with ASD aged 6-11	Equivalence test: two-sided test	Children with ASD demonstrated similar interaction patterns across all five conditions	Journal of Autism and Developmental Disorders (Impact Factor: 2.8)
Study IV: Pliska et al., 2026 (Appendix D)	Digital screening of children with ASD: Diagnostic accuracy of emotion recognition and visual preference tasks	1) Can an emotion recognition task be used to distinguish between children with and without ASD? 2) Can a visual preference task be used to distinguish between children with and without ASD?	Quantitative Study	24 boys with ASD aged 6-11 24 TD boys aged 6-11	1) Mixed logistic models 2) Mixed linear models 1) & 2) Decision trees	Children with and without ASD can be distinguished through emotion recognition and visual preference tasks When making a decision, both tasks should be considered in combination	BMC Psychiatry (Impact Factor: 3.6)

6.1 Answering the overarching research question

This chapter discusses the four successive studies from the doctoral dissertation to gradually answer the overarching research question: *Can the digital screening tool, which has been developed by the IDEAS consortium, contribute to the detection of boys with ASD?*

Technologies such as digital media are omnipresent in children's lives today and are present to a large extent (Alper et al., 2025; Baumgartner et al., 2025). A systematic review by Stiller and Mößle (2018) on the media usage of children and adolescents with ASD revealed that screen-based media are a preferred leisure activity for this group. However, the studies reported mixed evidence regarding screen media use in children with ASD compared to TD children (Stiller & Mößle, 2018). A comparison of studies on children's media use is only possible to a limited extent because they may have assessed media use differently. This would also explain the different results. According to the current state of knowledge, there is still no standardized, uniform questionnaire for recording media use, especially among children. In Germany, for instance, only the *Childhood, Internet, Media* (*Kindheit, Internet, Medien*; KIM) study (Medienpädagogischer Forschungsverbund Südwest, 2022) exists, and it was used as the basis for developing the questionnaire in Study I (*Media use*), which was then further developed in Study II (*Parental concerns*). The KIM study has examined media usage among children aged 6 to 13 in Germany every two years for the last two decades (Medienpädagogischer Forschungsverbund Südwest, 2022). However, the questionnaire of the KIM study is not publicly available and only records information such as media equipment and media ownership, as well as leisure activities and media engagement. To compare the results of media usage surveys within and between countries, an overall uniform – preferably standardized – questionnaire examining children's media usage must be developed and made freely available.

The results of Studies I (*Media use*) and II (*Parental concerns*) indicate that there is no difference in the frequency of digital media use between children with ASD and TD children. Since the parents in Study I also reported high levels of enjoyment regarding their children's use of digital media, it can be assumed that boys with and without ASD are familiar with and

enjoy using digital media. Furthermore, the parents gave high ratings for their children's confident use of digital media. Therefore, the assumption can be made that boys with and without ASD are capable of using and handling digital media. This fulfills an essential prerequisite for the feasibility and usefulness of digital screening for ASD by ensuring that the results are not affected by uncertainty when using a digital device. Based on Studies I and II, regarding the overarching research question, it can be assumed that the digital screening tool developed by the IDEAS consortium is acceptable and usable by both boys with ASD and TD boys. In general, it is important that this applies not only to TD or ASD groups. Children suspected of having ASD should use the screening tool, so there will be a mixed group of children, including those with and without ASD. Additionally, some children will have other impairments rather than ASD, for example, ADHD (Yates & Le Couteur, 2016). There is a high comorbidity between ASD and ADHD (Lord et al., 2020). Studies I and II do not provide any evidence to make any statements about children with other impairments and their media use. A study by Hill et al. (2024) showed similar screen time (collected via parental information) for both the ASD and ADHD groups. Therefore, it can be assumed that children with ADHD also enjoy using digital media and are able to use and accept it. However, there is still a small risk that some children, regardless of having ASD or not, may reject or be unable to use the digital screening tool.

All parents have beliefs and concerns about their children's media use (Benedetto & Ingrassia, 2021; Konca, 2022). These beliefs and concerns influence how children interact and grow up with media (Benedetto & Ingrassia, 2021; Konca, 2022). According to studies, a child's diagnosis of ASD can cause parents to be more concerned about their child's media use (Laurie et al., 2019; MacMullin et al., 2016). However, neither the study by Laurie et al. (2019) nor the study by MacMullin et al. (2016) explicitly examined the concerns of parents of children with and without ASD regarding media use. The survey study by Laurie et al. (2019) only included parents of children with ASD (N = 388). One finding was that concerns reported about technology correlated with longer technology use. Since other studies have already shown that children with ASD spend more time using media (Dong et al., 2021; Krishnan et al., 2021), it

can be assumed that parents of children with ASD are more concerned about their child's media use than parents of TD children are. In contrast, parents of adolescents with ASD (*n* = 139) and without ASD (TD; *n* = 172) participated in the survey study by MacMullin et al. (2016). One finding that supports the previous assumption is that parents of children with ASD were more likely to report that electronic use negatively impacted their child's life. The assumption that parents of children with ASD are more concerned about their child´s media use could not be confirmed by Study II (*Parental concerns*). Contrary to both studies (Laurie et al., 2019; MacMullin et al., 2016), Study II explicitly examined the concerns of parents of children with and without ASD, and no differences were found.

In light of concerns about the negative effects of media use on child development (Bartau-Rojas et al., 2018; Gür & Türel, 2022) – whereby Study II showed that parents of children with ASD have more concerns about this than parents of TD children – and given that children today are exposed to more digital media than ever before (Baumgartner et al., 2025), the concept of *virtual autism* is receiving more attention. *Virtual autism* refers to ASD-like symptoms caused by excessive media consumption (Zamfir, 2018). This field of research is still quite new, as the term was first introduced in 2018 by Romanian psychologist Marius Zamfir (Zamfir, 2018). According to the current state of knowledge, no studies have been conducted on parents' concerns about a potential link between their child's ASD symptoms and their media usage. Therefore, this topic was investigated in Study II (see Chapter 3). In this study, participating parents reported little to no concern about media consumption exacerbating their children's ASD symptoms. Therefore, it can be assumed that parents do not observe an increase in ASD symptoms in their child while using media. However, Study II also showed that parents of children with ASD are more likely to give their child access to digital media to self-regulate when they are not feeling well than parents of TD children. Study II provides complementary findings to those of Coyne et al. (2021) as well as Gordon-Hacker and Gueron-Sela (2020). Both studies were generally able to show, using parental survey data, that parents often give their children digital devices to help them self-regulate when experiencing negative emotions (Coyne et al., 2021; Gordon-Hacker & Gueron-Sela, 2020).

Parents of children with ASD likely give them digital media more often to self-regulate because screen media meet the sensory stimulation and solitary activity needs of children with ASD (Lane & Radesky, 2019; Mayer et al., 2024). Therefore, it is possible that ASD symptoms are not noticeable when consuming media, as this has a positive impact on behavior. This assumption can also be supported by the results of a study by Davchevska and Filipovski (2024). The results show that communication skills, which are impaired in children with ASD (American Psychiatric Association, 2013), can be enhanced through the use of digital media (Davchevska & Filipovski, 2024). Concerning the overarching research question, Study II (*Parental concerns*) indicates the need to examine whether ASD symptoms occur in a digital setting. ASD symptoms can only be recorded if they are visible in a digital setting. This is necessary for a digital screening instrument to differentiate between children with and without ASD. However, for this differentiation, it is important not only that children with ASD exhibit ASD symptoms in a digital setting, but also that TD children do not exhibit ASD-like symptoms as a result of media consumption. After all, high media consumption can lead to symptoms similar to those of ASD, as the keyword *virtual autism* illustrates (Al Moussawi et al., 2024; Bibi et al., 2022; Detroja & Bhatia, 2024; Harlé, 2019; Zamfir, 2018). Study II showed that parents' concerns about their child developing ASD(-like) symptoms due to media use are generally non-existent or almost non-existent, and do not differ between children with and without ASD. Therefore, it can be assumed that parents of TD children do not observe any ASD-like symptoms developing in their children as a result of media use.

The theory of media equation states that individuals perceive technology-mediated experiences similarly to direct, non-mediated experiences (Lee, 2008; Reeves & Nass, 1996) because interaction with media is perceived as social and natural, like real life (Reeves & Nass, 1996). This can be substantiated by the *rich-get-richer hypothesis* (Valkenburg & Peter, 2007), which posits that adolescents demonstrate continuity in social interaction across different environments. As a result, individuals who have difficulty communicating in person, such as those with ASD, are likely to face similar challenges in computer-mediated communication environments (Paulus et al., 2020). According to the current state of knowledge, no study has

statistically tested the media equation in children with ASD before. Instead, it has always been assumed that this is the case. However, studies are showing that children with ASD prefer digital presentations to live presentations (Cardon & Azuma, 2012) and may be attracted to computer-mediated communication (MacMullin et al., 2016; Shane & Albert, 2008; van der Aa et al., 2016). This preference and attraction probably stem from the fact that it provides less social information (Cummings et al., 2002; Ritzman & Subramanian, 2024). A study by Shane and Albert (2008) showed that children with ASD spend more time with media than with other activities on the weekend. However, the study only surveyed parents of children with ASD (n = 89), so it cannot be concluded whether this differs from TD children. In contrast, a study by van der Aa et al. (2016) compared the computer-mediated communication of an ASD group (n = 113) and a control group (n = 72) using an online questionnaire. The ASD group spent more time on computer-mediated communication than the TD group (van der Aa et al., 2016). However, the study by van der Aa et al. (2016) involved adults, so the results are not transferable to children. A study by MacMullin et al. (2016) used a parent survey to show that children with ASD (n = 139) spent more time on the Internet than TD children (n = 172). The difference, however, is minimal (ASD: M = 2.95, SD = 1.09; TD: M = 2.50, SD = 0.95). A study by Cardon and Azuma (2012) of n = 8 children with ASD, aged two to five, showed that visual attention was greater during the video presentation of a puppet show than during the live presentation. Visual attention was recorded during the live presentation when the child looked at the puppet and during the video presentation when the child looked at the iPad (Cardon & Azuma, 2012). Therefore, there is a risk that the result is not a preference for the digital presentation but rather a general interest in digital devices. This would support the assumption from Studies I and II that children with ASD would find digital screening interesting and would be willing to accept it. However, it is necessary to verify the media equation to ensure that children with ASD do not behave differently in a digital context or when interacting with an avatar than they do in face-to-face interactions. Study II (*Parental concerns*) also emphasised the need to investigate whether ASD symptoms occur in a digital environment. Study III (*Media equation*) was the first study to statistically examine the media equation and demonstrate its

validity in children's interactions with ASD in various digital-mediated conditions. Therefore, it can be assumed that boys with ASD aged 6 to 11 behave the same way in different digitally mediated conditions, such as interacting with an avatar, as they would in face-to-face interactions with a real person. In relation to the overarching research question, the necessary prerequisite that ASD symptoms occur in a digital setting can thus be considered fulfilled. Therefore, it should be possible to record ASD symptoms with a digital screening. This contributes to the usefulness of such a digital screening tool for the detection of boys with ASD. However, even if Study II does not suggest that TD children show ASD-like symptoms in a digital context, the media equation should still be verified to show that they do not behave differently in a digital context than in face-to-face interactions. As this was not examined in Study III, and according to the current state of knowledge, there is no data on this, no evident statement can yet be made in this regard (see Chapter 6.2). According to the media equation theory (Lee, 2008) and the *rich-get-richer hypothesis* (Valkenburg & Peter, 2007), it can only be assumed that TD children behave in the same way in digital settings as they do in face-to-face interactions.

Studies I to III (*Media use*, *Parental concerns*, *Media equation*) of this doctoral dissertation suggest that boys with ASD are able to use a digital screening and that ASD symptoms are visible in digital settings. However, the overarching research question is *whether the digital screening tool, which has been developed by the IDEAS consortium, can contribute to the detection of boys with ASD*. The final step is to determine whether the IDEAS consortium's digital screening tasks can distinguish between boys with and without ASD. As the IDEAS project focuses on language, facial expressions, and interactions, this doctoral dissertation focuses on additional tasks. On the one hand, emotion recognition can be used as a task to differentiate between children with ASD and TD children, as emotional impairment is a diagnostic criterion for ASD (Begeer et al., 2008; see Chapter 5). On the other hand, a visual preference task may be useful, as studies have often identified a decreased preference for social stimuli among children with ASD (Chita-Tegmark, 2016; Mukherjee et al., 2024; see Chapter 5). Therefore, this doctoral dissertation focuses on these tasks (emotion recognition

and visual preference), which have also been developed by the IDEAS consortium for the digital screening tool. Study IV (*Diagnostic accuracy*) demonstrated an accuracy rate of 81.25% for both emotion recognition and visual preference tasks. It can be concluded that these two tasks are suitable for digital screening. The emotion recognition task achieved a sensitivity of 91.67% and a specificity of 70.83%. In the visual preference task, however, it was the other way around, with a sensitivity of 70.83% and a specificity of 91.67%. In the emotion recognition task, 1 in 10 children with ASD would be misclassified as TD (false negative), and 3 in 10 TD children would be misclassified as ASD (false positive). In the visual preference task, 3 out of 10 children would be misclassified as TD (false negatives), and 1 out of 10 children would be misclassified as ASD (false positives). The IDEAS project aims to develop a digital screening tool that does not replace an ASD diagnosis. This tool should identify children who are likely to have ASD and should therefore undergo a diagnostic process for ASD in a subsequent step. The digital screening tool is not a diagnostic tool. It cannot be used to diagnose ASD. It either confirms or refutes the suspicion of ASD. Further diagnostic evaluations for ASD will be carried out for all children for whom screening continues to indicate a suspicion of ASD. Among these children are those who have been incorrectly identified as having ASD (false positive), which is a serious issue given the pressure on the system. These children are undergoing the diagnostic process for ASD even though they do not have ASD. This delays the process for those who do have ASD, meaning they will also receive support later. However, a false negative is more serious than a false positive because no further ASD diagnostic evaluations will be carried out for children for whom the screening no longer indicates ASD. Therefore, based on the contrasting sensitivities and specificities, these two tasks should be considered together to determine whether ASD is no longer suspected. Accordingly, children who are assigned to the TD group by both tasks (see Study IV) do not need to be further diagnosed for ASD. These children are not suspected of having ASD. However, children whose results differ between the two tasks should remain under suspicion and undergo diagnostic testing. There is a strong suspicion of ASD and thus a need for an

ASD diagnosis in children who are assigned to the ASD group based on both tasks. This means that the tool can contribute to the detection of ASD.

In summary, the overarching research question – *Can the digital screening tool, which has been developed by the IDEAS consortium, contribute to the detection of boys with ASD?* – can be answered based on the four successive studies of the doctoral dissertation as follows: Based on Studies I (*Media use*) and II (*Parental concerns*), it can be assumed that boys with and without ASD will not reject the digital screening tool and that both groups are able to use it. In addition, the digital screening tool can be used to record ASD symptoms, as Study III (*Media equation*) shows that boys with ASD behave in the same way when interacting with an avatar as they do in face-to-face interactions with humans. This means that symptoms of ASD can be elicited in a digital setting to record them. Based on Study II, it can also be assumed that TD children do not exhibit ASD-like symptoms in a digital setting. Studies I to III have created an important and necessary foundation, demonstrating the prerequisites for using the digital screening tool with this target group and for recording ASD symptoms. Finally, Study IV (*Diagnostic accuracy*) provides evidence that the digital screening tool can accurately distinguish between children with and without ASD. This distinction is made using emotion recognition and visual preference tasks developed by the IDEAS consortium. A combination of these two tasks should be considered. It can only be assumed that ASD is not present if the child is assigned to the TD group in both tasks. In the other two cases, where both tasks assign the child to the ASD group or assign them differently, suspicion of ASD remains, and an ASD diagnostic process should be carried out. In summary, the digital screening tool, which has been developed by the IDEAS consortium, can contribute to the detection of boys with ASD.

However, the four studies also have limitations, and there are challenges regarding the contribution of the digital screening tool to the detection of boys with ASD. Research desiderata can be derived from these limitations and challenges. The limitations and research desiderata are discussed in Chapter 6.2. On the other hand, in addition to the possibilities outlined in Chapter 6.1, there are implications for clinical and therapeutic practice. This is explained in Chapter 6.3.

6.2 Limitations and derivation of research desiderata

In answer to the overarching research question of *whether the digital screening tool, which has been developed by the IDEAS consortium, can contribute to the detection of boys with ASD*, the primary target group for the four studies was children with ASD. A limitation of all four studies (Studies I to IV) is the small sample size. However, the sample sizes are sufficient for the analyses performed in each study. It is important to note that children with ASD are a vulnerable target group because the prevalence of ASD is low, affecting only 1 in 100 children (with and without intellectual disability; Zeidan et al., 2022). To strengthen the results of Study I (*Media use*), media use was surveyed again in Study II (*Parental concerns*) using an updated questionnaire with a larger sample (Study I: n = 15 [ASD], n = 78 [TD]; Study II: n = 117 [ASD], n = 85 [TD]). However, the data in Study II originates from a new sample. Study I only included parents of boys, whereas Study II included parents of both boys and girls. Study II did not examine how gender influences children's media use. Nevertheless, the studies revealed similar results, which strengthens their validity. Additionally, Studies I and II can be compared since Study II supplemented the questionnaire from Study I with parental concerns and addressed the limitations of Study I. For example, parents may have interpreted "spending too much time with media" differently. Even from a scientific point of view, it is not clearly defined what "too much" means (e.g., KIM study; Medienpädagogischer Forschungsverbund Südwest, 2022). Consequently, Study II also asked parents how much time they considered to be an appropriate maximum for their child's media use. The difference in participation rates between the two groups in these two studies may be because Study II surveyed parents about their concerns regarding their children's media use. Questionnaires are usually completed by individuals for whom the topic is relevant. Laurie et al. (2019) suggested that parents' concerns increase after a child is diagnosed with ASD. Therefore, it is assumed that parents of TD children are less concerned about media use. A limitation of Study II is the potential for sample bias. It is possible that only parents who actively engage with their children's media use participated in the study. This could mean that the parents in

the study were more likely to have established rules regarding their children's media use and were less concerned about it. Consequently, the results may not be generalizable.

The possibility of analyzing children's media use across the 6- to 11-year-old age range as a whole, as was done in Studies I and II, should also be critically questioned. Children who are only six years old may not use media frequently or independently yet, whereas 11-year-olds already do so and have their own devices. The results of the KIM study (Medienpädagogischer Forschungsverbund Südwest, 2022) corroborate this notion, with parents indicating that children usually acquire their own devices as they grow older. For example, the percentage of children aged 6 to 11 who have their own smartphone rises from 9% (6-year-old children) to 58% (11-year-old children; Medienpädagogischer Forschungsverbund Südwest, 2022). Therefore, this age range may be too extensive. Cluster analyses should be conducted for smaller age groups. However, the sample size is too small, as Dalmaijer et al. (2022) recommend including 20 to 30 individuals in each subgroup. Therefore, Studies I and II should be expanded to include a larger sample size to conduct cluster analyses based on age. These results will confirm whether the age range of 6 to 11 years is appropriate or whether smaller age groups should be considered when developing the standardized questionnaire to survey children's media use. Nevertheless, other studies on children's media use in Germany have found that the most significant age difference occurs at age 11 (Ritterfeld & Lüke, 2021). Therefore, it can be assumed that this age range is still reasonably similar. In Study II (*Parental concerns*), age was only considered in the hierarchical regression analysis in relation to concerns, and it had no significant influence.

Regarding Studies I (*Media use*) and II (*Parental concerns*), it should be noted that information about the children's media use was collected from their parents. Parental information is usually not objective. It is possible that parents are not fully aware of their child's media use, which may slightly distort the results. However, a study by Wood et al. (2019) suggests that parents' assessments of their children's media use are consistent with the children's own. Laurie et al. (2019) highlighted that parents who are very concerned about their child's media use may overestimate it, while those who are less concerned may underestimate

it. Therefore, a new study should collect objective data alongside the parents' questionnaires about their children's media use. One approach would be to ask parents about the screen time displayed on the digital devices used by the child or to keep a diary of when their child uses media, which digital devices they use, and what they use them for. Another approach would be to examine the parents' assessments of siblings' media use, both with and without ASD. This would allow direct comparisons to be made between the results, since the same parent would be providing the information, and the household media equipment would be the same. The age difference between siblings should be minimal to avoid influencing the results with age-related factors. Additionally, it would be more meaningful to restrict the comparison of media use data to children with and without ASD from one class or school rather than comparing it to children from Germany as a whole, as was done in Studies I and II. This would allow for a better match of background variables. If the media's use of children with and without ASD and without intellectual impairment is surveyed, it is also necessary to ask the children themselves. This also helps to provide an understanding of why children with ASD enjoy using the media. Furthermore, a study by Matthes et al. (2021) revealed that excessive smartphone use by parents was associated with a loss of control over children's smartphone use. However, parents' media use was not included in Studies I (*Media use*) and II (*Parental concerns*) and was therefore not taken into account. Nevertheless, it is possible that children with high media exposure have parents with high media exposure (Study I), and that parents with extensive media use may be less concerned about their children's media use than parents with less frequent media use (Study II). Therefore, the questionnaire should be supplemented with information about the parents' media use.

The results of Study II (*Parental concerns*) show that parents of children with ASD are not concerned about the intensification of ASD symptoms through media use and suggest that symptoms may reduce through digital media. However, the latter was not recorded. To investigate the influence of media use on ASD symptoms, it is necessary to record both increases and reductions. Therefore, a longitudinal design should be used to examine whether media use intensifies or reduces symptoms over time. For this purpose, a list of behaviors

associated with *virtual autism* must be provided for parents to assess. Parents should also be asked to report their child's media use to learn more about potential changes in their child's behavior. Regarding the possible development of ASD-like symptoms in TD children and the intensification or reduction of ASD symptoms in children with ASD, it is useful to assess this using more than just a questionnaire. Given the limited research on this topic, further investigation through interviews would be beneficial. Parents should be asked about the behavior they observe in their children when they use media and the reasons why their children use media.

The small sample size is less significant in Study III (*Media equation*) because media equivalence is examined using a within-subject design. Unlike the classical hypothesis test (Lakens et al., 2018), Study III does not test for differences or rejection of the null hypothesis. Instead, it tests for equality. Due to the within-subject design and testing for equality, this is a unique design. However, it should be noted that the results of Study III cannot necessarily be generalized to other avatars or different experimental conditions. Media characters of the same sex are shown to be attractive to individuals (Hoffner, 2020). In all five conditions, the experimenter was a European woman, and all participants were boys. To ensure that the results are not dependent on the experimenter, the study should be conducted again by a different experimenter who is not similar to the original experimenter. As an alternative, condition 5 (avatar pre-recorded) could be conducted using various, randomly selected animated avatars, each corresponding to a different ethnicity and sex, to see if children would behave in the same way. Furthermore, the analyses should be repeated using a different method, such as the TOST bootstrap (Caldwell, 2025). If the results are the same, then they can be considered robust. As mentioned in Chapter 6.1, the media equation was only tested on children with ASD in Study III. However, TD children should also exhibit similar behaviors in a digital setting since the aim of the screening is to distinguish between children with and without ASD. Against the backdrop of *virtual autism*, it is crucial to determine if TD children exhibit behaviors in digital settings that resemble ASD-like symptoms. In that case, a digital

screening would be useless or of minimal use. Therefore, Study III should be repeated with TD children.

The results of Studies III (*Media equation*) and IV (*Diagnostic accuracy*) can only be applied to boys with and without ASD between the ages of 6 and 11 who have fluent, age-appropriate language competencies and no intellectual impairment. Since both studies were predominantly based on verbal interaction or responses, the results cannot be transferred to non-verbal children. Methodologically, it should be noted that the children's linguistic performance was not included in the studies. Regarding age-appropriate speech fluency and language skills, parental information was used, and the Test of Grammar Comprehension (German adaptation of the Test for Reception of Grammar; TROG-D; Fox-Boyer, 2023) was used to assess the children's language comprehension during testing. This ensured that difficulties with tasks (e.g., answering questions) were not due to a lack of language comprehension. However, it should be mentioned that the cultural appropriateness of the topics used in the warm-up/conversation situation was not considered in Study III (*Media equation*). Regarding Study IV (*Diagnostic accuracy*), it is important to note that most children with ASD were already receiving ASD-specific therapy, which may have affected the results. Not all children met the ASD threshold on the German version of the Social Communication Questionnaire (FSK; Bölte & Poustka, 2006), which was completed by their parents. Therefore, ASD symptoms may no longer be clearly visible in children with ASD. In this context, it should be emphasised that the statement that the children have an ASD diagnosis is based on information provided by the parents and verified solely based on current symptoms, as assessed using the FSK (Bölte & Poustka, 2006). Since children with ASD were recruited through autism therapy centers, where admission requires an ASD diagnosis, it can be assumed that the children actually have ASD. However, there is still a risk that the child has been misdiagnosed (see Kamp-Becker et al., 2018), so the diagnosis should be reviewed. In addition, Study IV (*Diagnostic accuracy*) revealed that five children in the ASD group and two children in the TD group had an additional ADHD diagnosis (see Chapter 5). However, the extent to which ADHD influenced group assignment was not controlled. Therefore, there is a

risk that the tool may incorrectly identify ASD in TD children due to ADHD symptoms. Thus, it is important to determine whether the screening tool can distinguish between children with ASD, children with ADHD, and TD children. Nevertheless, Study IV's two selected tasks were able to differentiate between children with ASD and TD children, strengthening the tasks' ability to distinguish between the two groups.

The screening tool developed in the IDEAS project is still in the development stage. Therefore, this doctoral dissertation uses a version of the tool that has not yet been carried out on a tablet. It still has a complex experimental setup involving tasks on a screen and an iPad behind it, making use of eye-tracking technology (see Pliska et al., 2023a), as well as a manual evaluation. To ensure that the tasks work solely on a tablet and can differentiate between the two groups, the digital screening must be finalized. In other words, the tasks should be integrated into an app that runs on an tablet, and the evaluation could be automated based on Study IV's results (*Diagnostic accuracy*). The final digital screening tool should be able to run automatically on a tablet, and it should also be able to record, evaluate, and interpret the results automatically. For example, the IDEAS project partner, Fraunhofer Institute for Digital Media Technology (IDMT), is currently reviewing language-related tasks and comparing manual and automated language recognition and evaluation methods, the latter of which uses artificial intelligence (Blank et al., in preparation). Based on the doctoral dissertation, no statement can be made about the final IDEAS app developed by the IDEAS consortium for digital screening of ASD. However, the results are promising that the final digital screening tool will contribute to the detection of children with ASD. In addition to establishing whether children enjoy using digital media and are able to use it (Studies I and II), it is also useful to understand how children with and without ASD use digital media. These results can then be used to enhance the automated process. Once the app has been finalised, it should be rechecked to see if the two tasks in Study IV can still distinguish between children with ASD and TD children. Additionally, proof of the sensitivity and specificity of the final screening tool for the entire task set is still pending. Comprehensive validation of the tool must also subsequently take place.

Furthermore, while this doctoral dissertation demonstrates the potential of the digital screening tool for the detection of ASD, the results are limited to differentiating between TD boys and boys with ASD without intellectual or language impairments, as only these children participated in Studies I, III, and IV. This specific target group was chosen as a first step because children with ASD and intellectual impairments are more likely to be diagnosed at an earlier age (Höfer et al., 2019) and because it is assumed that girls exhibit qualitatively different ASD symptoms to boys (Hodges et al., 2020; Hull et al., 2020; see Chapter 1). However, the clinical presentation of ASD is heterogeneous (American Psychiatric Association, 2013; Wawer & Chojnicka, 2022), meaning that digital screening must work for all children with ASD, including those with intellectual and language impairments, as well as for girls with ASD. Studies show that girls with ASD may be misdiagnosed, diagnosed later, or overlooked because of the female autism phenotype (Hodges et al., 2020; Hull et al., 2020). This also highlights the need for improved care for girls with ASD. First, interviews should be conducted with girls and women with ASD, as well as their parents and therapists, to discuss symptoms. In a retrospective study, girls, women, and parents should report on their experiences with and perceptions of childhood behavior, as well as how they would describe ASD. Therapists should report on the behaviors they observe in girls and women with ASD based on their practical experience. These interviews will be used to guide, cluster, and compare symptoms with the current diagnostic criteria for ASD. Based on the results, initial tasks can then be developed to determine whether they can differentiate between girls with and without ASD. In particular, Studies III (*Media equation*) and IV (*Diagnostic accuracy*) should be repeated with girls and young women with and without ASD. A digital screening tool for girls and young women with ASD should be developed to identify them earlier and provide appropriate support.

To investigate whether the digital screening tool can contribute to the detection of boys with ASD, Studies I to IV only involved children aged 6 to 11 (see Chapter 1). The age of six years, which is also often the age of school entry, is appropriate, as a study by Georgiades et al. (2022) has shown that symptoms of ASD in children plateau at around this age ("turning point"). In addition, the average age of diagnosis of ASD in Germany is 6;6 years (Höfer et al.,

2019). The age of six years was therefore chosen for these initial examinations, especially Studies III (*Media equation*) and IV (*Diagnostic accuracy*), as it was necessary to establish whether an ASD diagnosis was present. However, the actual aim of digital screening should be to contribute to the early detection of ASD. This means that studies should also be conducted with younger children. In the context of early detection, the IDEAS project also aims to use the final automated, digital screening tool to identify children on the waiting list for an ASD diagnosis who do not have ASD so that they can be removed from the list. It is not possible to make a statement about this based on the studies from the doctoral dissertation, since these only considered children with an ASD diagnosis or TD children.

6.3 Implications for clinical and therapeutic practice

The results of the four studies that address the overarching research question (see Chapter 6.1), as well as the limitations and derivation of research desiderata (see Chapter 6.2), have implications for clinical and therapeutic practice.

The digital screening tool is still in the development stage by the IDEAS consortium. Based on the preliminary version, which still requires a complex testing setting (see Pliska et al., 2023a) and manual evaluation, it has been demonstrated that this tool contributes to the detection of children with ASD. However, the IDEAS project aims to develop an automated digital screening tool that can be used on tablets. Therefore, the tool must be finalised. Studies III (*Media equation*) and IV (*Diagnostic accuracy*) indicate that an avatar and tasks for emotion recognition and visual preference can be used. Additionally, the decision trees in Study IV could be used to automate assignment to the ASD and TD groups. However, a study would be helpful to record how children with and without ASD use digital media concerning an automated implementation of the tool. These results could be crucial in improving the tool's feasibility. The new version of the tool must then be tested again to establish whether it contributes to the detection of children with ASD.

Furthermore, since Studies III and IV attempted to make the ASD group as homogeneous as possible (all participants were male with no intellectual or language impairments), the finalized app should be tested on boys and girls with intellectual and

language impairments. This will account for the high heterogeneity of ASD symptoms (American Psychiatric Association, 2013; Wawer & Chojnicka, 2022) and test the tool's ability to distinguish in a more heterogeneous group. For this purpose, the emotion recognition task, which is currently based on children's verbal statements, must be adapted into a non-verbal version and verified. For example, the basic emotions could first be introduced using emojis. Then, for each picture of a child displaying an emotion, all the emojis will be presented, and the child should click on the one that they think represents the emotion displayed by the child in the picture. The visual preference task is already non-verbal. More tasks can then be developed within this context. Because of the high comorbidity of ASD with ADHD (Lord et al., 2020), it is important to evaluate how accurately the digital screening tool can differentiate between children with ASD, TD children, and children with ADHD. In the context of child and adolescent psychiatry, the digital screening tool can be examined with not only children with ADHD, but also other target groups, such as those with language development disorders, anxiety disorders, social communication disorder, and obsessive-compulsive disorders, to screen for differential diagnoses (cf. Yates & Le Couteur, 2016). If the digital screening tool can distinguish between ASD and TD, as well as between ASD and differential diagnoses, based on the tasks, it could be a valuable addition to child and adolescent psychiatry and the detection of ASD. In some cases, it is possible that the tool could indicate a suspicion of one of the other diagnoses. This is particularly important because children who are not identified as being suspected of having ASD during screening, and who therefore do not undergo further ASD diagnosis, may be suspected of having a differential diagnosis instead. This leads to a specific diagnostic process for this differential diagnosis.

Even if the final tool does not differentiate between children with ASD and TD children with sufficient diagnostic accuracy, it can still contribute to therapeutic practice. The tool's tasks have been selected and developed according to diagnostic criteria (see Kachel et al., 2025), i.e., the areas in which children with ASD exhibit different behaviors than TD children. If children with ASD exhibit different behaviors than TD children when performing these tasks, this information can help therapists, such as occupational therapists, support the child in this area.

The same applies to children with suspected differential diagnoses. Additionally, the tool can be used in schools to provide special education teachers with suggestions for areas of support. Therapists at autism therapy centers could also use the tool to identify areas where support is needed and the child's strengths.

Overall, the screening and subsequent diagnosis process for ASD is only the first step. This must be followed by therapy and support. However, accessing support for children with ASD faces the same obstacles as diagnosis: long waiting times (Bundesministerium für Forschung, Technologie und Raumfahrt, 2025). This obstacle is addressed, for example, by the AuThenTo project (game-based autism therapy for children; 2025–2028; Bundesministerium für Forschung, Technologie und Raumfahrt, 2025). With a digital intervention for children with ASD, long waiting times for therapy places can be bridged, and ongoing therapy can be supported (Bundesministerium für Forschung, Technologie und Raumfahrt, 2025). Furthermore, the IDEAS project's screening tool can be further developed as a digital support tool that can be used at home. Based on the screening tasks, it can be adapted into training games. For example, the emotion recognition task can be expanded to include showing video clips and having the child click on the person who is currently angry. Another option is to show the child pictures of individuals (children and adults) of different ethnic backgrounds with various emotional expressions on a tablet. Then, the child should cluster the pictures based on the individuals' facial expressions and assign each picture to an emotion.

The overall aim would be to develop the digital screening tool into a medical product. This product could be used in pediatric practices, for example. The potential aim of the digital screening tool is to establish whether ASD is suspected. If there is any suspicion, further steps can be taken, such as diagnostic testing. The screening tool can also be used to address the long waiting list for an ASD diagnosis. It could identify children on the waiting list who are suspected of having ASD and those who are unlikely to have it. This would remove the latter group from the waiting list and relieve the burden on the healthcare system, which has limited personnel capacity (Kamp-Becker et al., 2021). As mentioned in Chapter 6.1, only children

assigned to the ASD group by both tasks, or assigned differently, should continue with the ASD diagnostic process, because there is still suspicion of ASD. Children who are assigned to the TD group in both tasks can be removed from the waiting list for an ASD diagnosis, as they are not suspected of having ASD. Studies III (*Media equation*) and IV (*Diagnostic accuracy*) only tested the preliminary screening tool with children who had already been diagnosed with ASD and TD children. The digital screening tool must therefore be tested on children who are initially suspected of having ASD. After that, all children, including those for whom the screening tool does not indicate ASD, must undergo the diagnostic process for ASD to ensure specificity. After the diagnostic process, it must be verified that the extent to which the screening tool assigns children to the ASD and non-ASD groups matches the given diagnosis.

A diagnosis of ASD is made based on observed symptoms and behavioral descriptions (see Hodges et al., 2020). Screening tools such as the FSK (Bölte & Poustka, 2006) record the child's behavior as described by their parents, meaning the behavior is subjectively recorded over a longer period. In contrast, the IDEAS consortium's screening tool provides an objective, observational record of a child's symptoms at a single point in time. For this reason, it makes sense to use a parent questionnaire alongside the digital screening tool to record symptoms to decide whether to suspect ASD. Thus, a questionnaire that also records behaviors related to *virtual autism* should be developed to avoid falsely attributing ASD-like symptoms resulting from high media consumption to ASD. A special education teacher who suspects that a child has ASD could also use this tool in combination with a parent questionnaire. Based on the results, the teacher can discuss further steps with the parents, such as providing support or initiating a diagnosis, if necessary. In this context, it is particularly important that the questionnaire also covers *virtual autism*, so that teachers are not led to suspect ASD in a child due to concerns, prejudices, or a lack of information. Against this background, teachers and parents must be informed and educated about *virtual autism* from the outset. Overall, the screening tool should only be used by educational and, preferably, clinical professionals. This means that parents should not use the tool at home with their children alone, as this could lead to misuse of the tool and false hopes, since they do not know

exactly what the results mean. In an interview study by Crane et al. (2018) in the United Kingdom, parents of children with ASD (*n* = 10) reported feeling aimless and lacking adequate support after the diagnostic process. It is therefore important that specialist staff explain the results to the parents and provide support to both parents and the child with ASD, e.g., by helping them to take the next steps.

As the digital screening tool contributes to the detection of children with ASD, further examination is needed to establish whether it can also contribute to early detection. Identifying ASD earlier allows for the provision of specific support sooner, resulting in better developmental outcomes (cf. Lin et al., 2022; Wiggins et al., 2006). Already during the second year of life, early predictive behavioral markers of ASD can be observed (Zwaigenbaum et al., 2015). For example, Pierce et al. (2016) demonstrated that a visual preference task could distinguish between children with and without ASD in toddlers between one and four years of age. This offers promising results that the digital screening tool, which has been developed by the IDEAS consortium, can also contribute to early detection. Therefore, the digital screening tool should also be tested with younger children (under six years of age). It can be assumed that children under six years of age can handle the digital screening tool, since studies show that children with ASD are exposed to media at a younger age than TD children (Cardy et al., 2021; Krishnan et al., 2021; Slobodin et al., 2019). As soon as parents have their first suspicions, which a meta-analysis by Höfer et al. (2019) shows can occur by the second year of life, they can take their child to the pediatrician. The pediatrician will then use the digital screening tool in addition to a questionnaire. This can shorten the period of uncertainty that parents experience regarding their child's development. If the tool indicates a suspicion of ASD, further ASD diagnostic steps can be initiated early, and therapists can begin providing support based on the results of the tool.

7 Conclusion

In summary, the four studies relevant to the doctoral dissertation answered the overarching research question: *Can the digital screening tool, which has been developed by the IDEAS consortium, contribute to the detection of boys with ASD?* This doctoral dissertation

demonstrates that boys with ASD can use and are familiar with digital media, and that they behave in digital settings similarly to how they behave in face-to-face situations. Therefore, it can be assumed that they are able to use the digital screening tool and will not reject it. Additionally, symptoms of ASD would be visible in a digital setting and could be elicited through digital screening. The doctoral dissertation also demonstrated that the emotion recognition task and the visual preference task both achieved good diagnostic accuracy. In conclusion, the overarching research question can be answered as follows: The digital screening tool, which has been developed by the IDEAS consortium, can contribute to the detection of boys with ASD, as combining emotion recognition and visual preference tasks can differentiate between children with ASD and TD children.

This doctoral dissertation presents promising results, suggesting that further development of the digital screening tool could contribute to relieving resource-limited settings in clinical practice. If the automated digital screening tool can differentiate between children with ASD and TD, even with heterogeneous samples, and correctly sort those children suspected of having ASD who do not have ASD, it could relieve the burden on the healthcare system, alleviate family uncertainty, and contribute to earlier support and intervention. Furthermore, if the screening tool can distinguish between children with ASD and TD in younger children, paediatricians will be able to reinforce parents' suspicions based on the screening results. This will enable them to take further steps towards diagnosis sooner, providing support for families and children.

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Appendix A: Study I

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Toward digital participation in individuals with Autism Spectrum Disorder

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Introduction: Digital participation might have great potential for the everyday lives of individuals with Autism Spectrum Disorder (ASD). Previous research suggests that children with ASD enjoy and favor usage of digital technologies. As informative research on this topic is still sparse, this paper makes a contribution toward a better understanding of media usage in children with ASD.

Methods: Parents of 15 boys aged 6 to 11 diagnosed with ASD in Germany were asked about their children's media usage. For comparison, parents of 78 typically developing (TD) children were surveyed online.

Results: Statistical analyses reveal no differences between boys with and without ASD in media use, frequency, and reasons for use. However, there is a significant group difference in parents' perceptions of difficulty of restricting their child's media use: Parents of children with ASD reported greater difficulties of restriction of their child's media use than parents of TD children.

Discussion: Digital media is an integral part of the daily lives of children with ASD and has the potential to increase the social inclusion of people with ASD through digital participation.

KEYWORDS

Autism Spectrum Disorder, media use, digital media, digital participation, neurodevelopmental disorder

1. Introduction

Since the 1988 signature movie "Rain Man," Autism has been a popular topic in entertainment media. For example, there are some recent television series (i.e., "The Good Doctor," "The Big Bang Theory") where the main character shows the neurodiverse condition of Autism Spectrum Disorder (ASD) or a potential diagnosis is at least discussed. The protagonists with ASD are hereby often portrayed with extraordinary abilities presenting ASD in a rather favorable light (Ressa, 2022). However, ASD is classified as a serious neurodevelopmental disorder which is characterized by persistent deficits in social interaction as well as communication and by restricted, repetitive, and stereotyped patterns of behavior, interests, or activities (American Psychiatric Association, 2013). For example, persistent deficits in social interaction and communication include impairments in pragmatic language (Filipe et al., 2020). Pragmatic language can be understood as the ability to use and interpret language effectively in communicative exchanges (Milligan et al., 2007). The clinical presentation of ASD is heterogeneous, and symptoms are multifaceted and varies widely between individuals (American Psychiatric Association, 2013; Wawer and Chojnicka, 2022). For this reason, Autistic disorder, Asperger's disorder, childhood disintegrative disorder, and pervasive developmental disorder not otherwise specified in DSM-IV have been condensed into one diagnosis in DSM-V: Autism Spectrum Disorder (see Hodges et al., 2020).

The prevalence of ASD diagnoses has increased worldwide (Chiarotti and Venerosi, 2020; Bougeard et al., 2021; Zeidan et al., 2022). This increase reflects the combined effects

of, for example, a raised community awareness – which is particularly an improvement – and progress in case detection, enabled by significant improvements in early identification (Zeidan et al., 2022). A systematic literature review by Bougeard et al. (2021) shows that a prevalence of ASD ranged between 38:10,000 and 155:10,000 in European children aged 4 to 8 years in the period 2014 to 2019. Until 2012, the global estimate of ASD prevalence was 62:10,000 (Elsabbagh et al., 2012) and is nowadays estimated to have risen up to 100:10,000 (Zeidan et al., 2022). This means that approximately 1 in 100 children worldwide receives a diagnosis of ASD (Zeidan et al., 2022).

Boys have a higher prevalence of ASD than girls (Elsabbagh et al., 2012; Jiménez-Muñoz et al., 2022; Zeidan et al., 2022). In contrast to a previously reported 4:1 male-to-female ratio, a meta-analysis by Loomes et al. (2017) estimates the true male-to-female ratio to be closer to 3:1. Girls may be misdiagnosed, diagnosed later, or overlooked because of the female Autism phenotype (Hodges et al., 2020; Hull et al., 2020). "Female Autism" has been described as qualitatively different from typical "male Autism" (Hull et al., 2020). Ongoing research therefore strives to explain these sex differences while taking the possibility into account that females are better in masking symptoms which makes them less likely to receive the ASD diagnosis (for a review see Lockwood Estrin et al., 2021).

Generally, gold standard methods of diagnosing ASD typically take many hours to complete and contribute to long waiting times for concluding a diagnosis (Tariq et al., 2018). This long wait creates not only uncertainty for the entire family (Wiggins et al., 2006) but also delays the start of family support and child therapy (Tariq et al., 2018). This delay can have incremental effects as an early start of intervention has been proven to result in better developmental outcomes (Wiggins et al., 2006; Lin et al., 2022). Valid screenings administered at an early age could contribute substantially to cutting the waiting list. In many countries diagnosis of ASD is a necessary precondition for receiving treatment. A metanalysis conducted over 35 countries yielded a mean age of first diagnosis of 60.48 months (5.5 years, range: 30.90 to 234.57 months; van't Hof et al., 2021). Children with intellectual disabilities (IQ < 85) are hereby diagnosed much earlier than children without intellectual disability (IQ ≥ 85; Höfer et al., 2019). In Germany, the mean age of first diagnosis is with 78.5 months (6.5 years) already reaching school age, although most parents report already having had concerns when their child was about 2 years old (Höfer et al., 2019). The longer waiting time to be eligible for diagnostics in Germany compared to other countries highlights the need for improved forms of care for suspected cases of ASD in Germany (Höfer et al., 2019).

The authors are part of the recent grant-funded project IDEAS (Identification of Autism Spectrum Disorder using speech and facial expression recognition) which aims to develop an automated screening tool for the early detection of ASD. Since such an automated tool requires mediated input, we investigate the usefulness of various media formats to elicit relevant symptoms (Pliska et al., 2023) and aim to achieve a differentiation as selective as possible between autistic and typical development using this tool. As a necessary basis, media usage and competence in children with ASD must be compared to typically developing (TD) children to further understand usage and acceptance of digital technology in this particular group.

1.1. Media usage in individuals with ASD

"Digital technology is considered the main facilitator in social inclusion and community living in people with disabilities" (Glumbić et al., 2022, p. 98). It has been consistently reported that children with ASD are particularly attracted by digital technologies (Mazurek and Engelhardt, 2013; Laurie et al., 2019; Scholle et al., 2020), especially screen-based media and hereby namely video games. The time that children with ASD spend with digital media typically exceeds the time invested by TD peers (Krishnan et al., 2021). Several studies have shown that using media-based learning is well accepted in children with ASD (Lin et al., 2013) and in case of doubt would be preferred to other formats. For example, a study by Brunero et al. (2019) can support the preference of children with ASD – especially high-functioning boys – for digital media to support learning activities. Some authors argue that interacting with computers can be particularly enjoyed by children with ASD (Valencia et al., 2019; Arshad et al., 2020) because the digital space is perceived as a safe and trusted environment (Valencia et al., 2019). Moreover, the internet offers a virtual space largely free of face-to-face interaction, which often poses a stressful demand on individuals with ASD (Pinchevski and Peters, 2016).

1.1.1. New media for clinical diagnosis

The use of new technologies for clinical diagnostic purposes has also been discussed and investigated. For example, Alcañiz et al. (2022) successfully used an eye-tracking paradigm in a virtual environment to differentiate between children with ASD and TD children based on visual attention behaviors. Visual attention was used to measure perceiving and extracting socially relevant information. With regard to the diagnostically very relevant area of mimic expression, Forbes et al. (2016) indicate the feasibility of 2D-virtual reality (VR) in eliciting mimicry, thus confirming that participants with ASD imitate less than TD individuals when interacting with avatars. In sum, the results suggest that the behavior that people with ASD exhibit in face-to-face situations – e.g., in diagnostic settings – might be equally present when they interact with and respond to avatars (Forbes et al., 2016). This parallelism of behavior in real and virtual environments has been coined *media equation* (Reeves and Nass, 1996; Lee, 2008) and opens further potentials for the implementation of digital media in (automated) diagnostic or screening approaches.

1.1.2. New media for clinical intervention

Some authors proposed the effectiveness of new and especially immersive technology even for clinical intervention (Valentine et al., 2020; Robles et al., 2022). The term immersion describes a mediated experience in which the sense of mediation vanishes, and the experience feels as if being real (Biocca, 2002). For example, a VR system was evaluated to improve emotional skills in children with ASD (Lorenzo et al., 2016). In addition, interactions with autonomous virtual humans were successfully evaluated to help children with ASD in learning social skills (Milne et al., 2018). A systematic review by Cheng and Bololia (2023) examined whether augmented reality (AR) supports children with ASD in developing or promoting social skills. Findings suggest the effectiveness of AR e.g., for recognition of facial expressions or social reciprocity in

children with ASD (Cheng and Bololia, 2023). The use of video games as therapeutic tools in children with ASD was evaluated in a systematic review by Jiménez-Muñoz et al. (2022). The reviewed studies show that video game-based therapeutic interventions are generally effective with small effect sizes, and helpful in the development of children with ASD. For example, they show a decrease in repetitive movements after intervention with exergames in children with ASD (Jiménez-Muñoz et al., 2022). Exergames are video games that require physical movement to play (Benzing and Schmidt, 2018).

1.1.3. Media for educational purposes

Complementary or additive to intervention approaches, the use of mobile and interactive learning technologies – so-called *lean forward-media* in contrast to *lean back-media* (e.g., TV) – in the education of older children with ASD has grown impressively (Stathopoulou et al., 2020). Several studies have suggested that usage of such modern technology can facilitate learning of individuals with ASD (Valencia et al., 2019). Some interesting examples of new technology include sensors, VR, virtual agents, and AR (Valencia et al., 2019). Studies show the potential of AR to support children with ASD in school, especially for participation and learning (Hashim et al., 2021; Assis Freire de Melo et al., 2022). Finally, studies have investigated the use of technology and computer-based interventions to teach language and social skills to individuals with ASD (Grynszpan et al., 2014). The results of these investigations provide evidence for the overall effectiveness of technology-based training (Grynszpan et al., 2014). There is also good evidence that computer-based learning is both acceptable and potentially beneficial for children with ASD (Lin et al., 2013).

1.1.4. Self-selected media use and the debate of negative effects

As summarized above, technology and media have been successfully used for clinical (diagnosis and intervention) as well as educational purposes for children with ASD. Most of the authors hereby refer to the assumption that children with ASD are especially attracted to digital media but consistently refrain from evaluating this assumption. Possibly, research on this topic is still sparse because media usage and ASD research is a relatively new matter (see Stiller and Mößle, 2018), but there is a risk that the assumption has simply been nurtured by the observation of social avoidance in a population with ASD and the assumed potential for compensation through virtual environments. Despite the ubiquitous impact of media in the childhood of today's adolescents, an analysis of the literature over the past 5 years revealed limited research output addressing media use in everyday lives of individuals with ASD: one systematic review (Stiller and Mößle, 2018) and two additional studies that provide insights into the media usage of children with ASD (Lane and Radesky, 2019; Laurie et al., 2019).

Most informative is the systematic review by Stiller and Mößle (2018) on media usage by children and youths with ASD. Forty seven studies from the years 2005 to 2016 were included to determine the significance of media in the lives of these children and adolescents. Consistent across all studies, screen-based media was a preferred leisure activity of children with ASD. The most popular medium was television, followed by playing video or computer games. However, other leisure activities (e.g., outdoor play) were neglected due to the preference for screen media as a leisure activity. Compared to TD children, the studies reported mixed evidence on screen media use. However, children with ASD spent significantly less time using social media than children without ASD. Stiller and Mößle (2018) were able to identify both positive and negative effects as a result of screen media use. For example, positive effects were seen in improved social, motor, and cognitive skills, whereas negative effects manifested in less sleep, less physical activity, oppositional behavior, and problematic media use. However, as the vast majority of the reviewed studies were conducted in North America, Stiller and Mößle (2018) highlight a research gap for several European countries, including Germany, where media usage differs and is also criticized more often. In Germany, only the large-scale and regularly conducted survey Childhood, Internet, Media (*Kindheit, Internet, Medien;* KIM), which has been conducted regularly since 1999, is available. The KIM study examines the value of media in the everyday lives of a representative sample of German-speaking children (ages 6 to 13; Feierabend et al., 2021). Since 2006, the KIM study has been conducted every 2 years. However, this study reports on children in Germany in general and does not differentiate between different clinical populations, so there is no disaggregated data on children with ASD.

One of the few European-based approaches stems from Laurie et al. (2019) who report online survey data from 388 parents of children with ASD in the UK ($n = 131$), Spain ($n = 134$), and Belgium ($n = 123$). The study addresses the overarching question of how children and older individuals with ASD use technology at home. Participants were split into five groups based on the respective age ($\leq$5, 6–12, 13–17, 18–25, $\geq$26 years). The online survey–which ran for approximately 2 months in each country–collected the parent's demographics, child profiles, information about technology use at home, and attitudes toward technology use. The most commonly reported devices available were tablets and PC/laptops, whereas digital games, YouTube, listening to music, and looking at or taking photos were the most commonly reported functions of technology use already 5 years ago. The study provides evidence that adults and children with ASD were competent in the use of a wide variety of devices and interface types. In addition, the study reported that parents might be concerned about their children's use of technology, particularly the amount of time spent with devices and subsequent social consequences (Laurie et al., 2019). Regarding the specific (and already very heterogeneous) characteristics of individuals with ASD, it is important to examine media use data specifically for a population without comorbidities.

The implementations and evidence of effectiveness in diagnostics, intervention, and learning contexts described above can be seen as positive effects of media affinity in children with ASD. They exploit the potential of new technologies to adapt new offerings to the needs of individuals with ASD or to adapt existing approaches. At the same time, potential negative effects must be equally included in the analysis of media use. These have been touched upon in previous research and include problematic use of media and possible links to the intensity of autistic symptoms. Lane and Radesky (2019) hypothesize in a brief report that children

with ASD may be at higher risk for problematic media use with portable and interactive media devices. Here, problematic media use means high levels of media use that crowd out sleep, exercise, homework, or play. The authors claim that no study found a definitive connection between early media consumption and the occurrence of ASD, referring to a debate that occurs again and again in social media as well as in the scientific community, namely whether high media consumption could exacerbate or even trigger symptoms of ASD. Impetus for this debate was recently provided by a study by Dong et al. (2021) who examined the screen time of 57 TD children and 101 children with ASD in detail. Their results support previous findings that screen time was significantly longer in the group of children with ASD than in the group of TD children. In their analyses, the ASD-related symptoms became more pronounced with increasing screen time (Dong et al., 2021). Some authors use evidence such as this to claim that media exposure might even cause ASD (Slobodin et al., 2019; Dong et al., 2021). As a consequence, concern about early exposure to screen media and its potential impact on developmental delays including ASD is expressed (Heffler et al., 2022). Nevertheless, the described findings do not provide any information on the direction of a possible causal relationship, which remains unclear. Longitudinal investigations are needed such as the study by Heffler et al. (2020), who examined the association between screen media exposure and risk for diagnosed ASD or ASD-related symptoms in children at 2 years of age. Their finding among a large sample of 2,152 children was that less TV and video exposure and more interactive caregiver-child play at age 1 year were associated with fewer ASD-related symptoms at age two (Heffler et al., 2020). Nevertheless, other study results suggest that the premise of the named authors may be a fallacy since children with incipient social communication problems, such as those with ASD, simply seem to be more likely to prefer object-based play, which includes television and digital devices (Lane and Radesky, 2019). However, studies show that the symptoms of ASD are associated with high and early media use (Heffler et al., 2020; Krishnan et al., 2021). The question of a causal link or effective use of digital media to support ASD seems premature given the sparse knowledge base regarding everyday use of media in individuals with ASD. This study aims to provide insight on this topic.

1.2. Research questions and hypotheses

Our literature review indicated that research on the topic of media use in children with ASD was still sparse and data on children with ASD in Germany were missing (Stiller and Mößle, 2018). In the general population, there was an exponential increase in the use of media devices by children already during elementary school age (Spina et al., 2021), also in Germany (Feierabend et al., 2021). This was the age period in which ASD typically should already be diagnosed (van't Hof et al., 2021). A meta-analysis including 35 studies (n = 66,966 individuals with ASD) found a current mean age of 60.48 months (5.5 years) for the initial diagnosis of ASD (range: 30.90 to 234.57 months; van't Hof et al., 2021). Therefore, most children at 6 years of age and older were likely to have a valid diagnosis of ASD. Since sex differences in ASD were vast (Elsabbagh et al., 2012; Jiménez-Muñoz et al., 2022; Zeidan et al., 2022) and not yet fully understood (Hull et al., 2020), boys and girls with ASD should be considered separately. To take a further step into informing about media usage in individuals with ASD compared to TD children, we were proposing the following research question:

How does the media use of boys with ASD age 6 to 11 differ from the media use of TD boys in Germany?

Specifically, we expected (1) boys with ASD to use digital media at significantly higher rates (Dong et al., 2021; Krishnan et al., 2021). Furthermore, we assumed (2) different usage motives between boys with ASD and TD boys (e.g., Lane and Radesky, 2019). We expected that boys with ASD would be less likely to use media for social purposes than TD boys (e.g., Stiller and Mößle, 2018). We also hypothesized (3) that confidence in using digital media, enjoyment of digital media, a sense of non-mediation or *being there* while being involved with new media (so-called *presence* or *immersion*; Biocca, 2002), parents' ratings about their child's digital media behavior, and parents' perceptions of difficulty of restricting their child's media use differ between children with ASD and TD children. We expected higher scores in parents' assessments of children with ASD.

2. Method

2.1. Participants

Families with children diagnosed with ASD were recruited at an autism therapy facility in a German metropolitan area in spring 2023 in the context of a superordinate research project on the medial elicitation of ASD-associated symptoms (IDEAS). Children participated in a pilot testing to evaluate suitability of media usage formats for screening purposes. In addition, parents answered a questionnaire on media usage the results of which were reported in the current study. For the TD group, participants were recruited using an online survey through private and professional contacts via social media, e-mail distribution lists, and organizations. The target group were boys between 6 and 11 years who were enrolled in elementary school. Although ASD encompassed a wide spectrum on intellectual capacities, the study focused on age-appropriate intellectual abilities that allows comparison with TD. Recruitment resulted in a group of 15 boys with diagnosed ASD with an average age of 8.93 years (SD = 1.79). For the TD group, 78 boys at an average age of 8.21 (SD = 1.57) were included. According to the parent's report, none of the boys in both groups had an intellectual disability and none in the TD group was ever suspected of a diagnosis of ASD. Regarding socio-economic status (SES), we find higher educational levels in the TD group for both parents (see Table 1).

2.2. Measures

Data on the children's media usage were collected using an online survey for parents. This instrument included questions on the availability of media in the home, the frequency of use of these media, and individual reasons for using digital media. Parents were also asked how confident they perceive their child in using digital media, how much their child seems to enjoy it and the estimated

TABLE 1 Distribution of parents' highest educational degree.

Education degree	Father's highest level of education		Mother's highest level of education	
	ASD group ($n = 14$)	TD group ($n = 78$)	ASD group ($n = 15$)	TD group ($n = 78$)
Less than high school diploma	35.71% ($n = 5$)	19.23% ($n = 15$)	33.33% ($n = 5$)	10.26% ($n = 8$)
High school diploma	57.14% ($n = 8$)	26.92% ($n = 21$)	46.67% ($n = 7$)	24.36% ($n = 19$)
College diploma	7.14% ($n = 1$)	53.85% ($n = 42$)	20% ($n = 3$)	65.39% ($n = 51$)

degree of *immersion* (sense of non-mediation or being *there*) during usage. Finally, parents were asked whether they believe that their child spends too much time on digital media and whether they had difficulties limiting their child's media usage. For most items, a ten-point Likert scale ranging from *not at all* to *very much* was applied. Availability of media in the household was assessed by frequency of media exposure to PC/laptop, tablet, mobile phone, game console, TV, radio/podcast, digital assistants, SMART-Toys (networked toys), and others. Exposure was evaluated on an ordinal scale ranging from *never* (coded as "0"), *sometimes* (once/several times a week; coded as "1") to *often* (every/almost every day; coded as "2"). These item response options have been modified from the KIM study (Feierabend et al., 2021). In addition, reasons for using digital media were examined including: playing entertainment games, playing learning games, viewing photos, taking photos, listening to music/audiobooks/podcasts, watching movies/videos, and chatting/interacting with others and other (open space for text additions).

2.3. Data analysis

Descriptive and statistical analyses were performed using R (R Core Team, 2022, version 4.2.2). For group comparison, Mann-Whitney-U-tests were used concerning availability of media in the home (individual tests per device/application) and the children's reasons for media usage (comparison per individual activity, e.g., playing learning games, chatting...) as well as self-assessment questions to parents (all 10-point scaled). In addition, frequency responses and percentages were considered for each question. Percentage was calculated by dividing the total number of responses for a given question by the number of respondents who participated in that question. To look at possible relationships between the variables, Spearman's correlations were calculated for the 10-point scaled questions. Finally, a two (TD) to one (ASD) manual matching was performed to account for the fact that parents of TD children had higher educational attainment. The matching variables were age, father's, and mother's educational attainment. Comparisons between matched participants were also performed using Mann-Whitney-U-tests. Overall, approximate significances were calculated for datasets with sample sizes >50 and exact significances for sample sizes <50.

3. Results

Table 2 displays the availability of digital media in the home and the reported frequencies of digital media usage. Over 86% of both the ASD and TD group had access to a PC/laptop, tablet, mobile phone, TV, radio/podcast/CD player/audiobook at home. Eighty percentage in the ASD group and over 65% in the TD had a gaming console available at home. The availability of digital assistants and SMART Toys at home varied between 40% and 51% in both groups. In the ASD group ($n = 15$), 86.67% ($n = 13$), and in the TD group ($n = 78$), 87.18% ($n = 68$) had five or more than five different digital media available in the home. There was no significant difference between the two groups in the number of digital media available in the home ($p > 0.05$). Also, Mann-Whitney-U-tests revealed no differences in exposure to each digital medium between both groups ($p > 0.05$).

The children's reasons for using digital media are shown in Table 3. Most Mann-Whitney-U-tests on the individual reasons for using digital media did not reach statistical significance. Significant differences in media use were found for playing entertainment games ($p = 0.007$). The mean score for using digital media to play entertainment games was higher for children with ASD ($M = 1.67$, $SD = 0.49$, $n = 15$) than for TD children ($M = 1.14$, $SD = 0.69$, $n = 76$). According to Cohen (1988, 1992), this effect was small ($r = 0.29$).

Mann-Whitney-U-test between groups was calculated with each individual parent self-report question about their children and media (see Table 4). Here, only the variable that the parents have difficulties limiting their child's media usage became statistically significant ($U = 285$, $z = -3.20$, $p = 0.001$) with a moderate effect ($r = 0.33$). The mean score was higher for children with ASD ($M = 4.93$, $SD = 2.84$, $n = 15$) than for TD children ($M = 2.57$, $SD = 2.11$, $n = 77$).

Table 5 displays correlations between the self-assessment questions to parents about their children and media. Significant correlations were found between assessment of the child's confidence in using digital media and enjoyment of digital media usage ($p < 0.001$), as well as belief that their child spends too much time using digital media ($p = 0.028$). Furthermore, significant correlations occurred for enjoyment of digital media usage and immersion ($p < 0.001$) as well as belief that their child spends too much time using digital media ($p < 0.001$) and between the latter two ($p = 0.006$). Moreover, there was a significant correlation between belief that their child spends too much time using digital media and difficulties limiting their child's media usage ($p < 0.001$).

To control for the higher SES in the TD group, a 2:1 manual matching was performed on age, father's and mother's educational attainment (see Supplementary Table 1 for details). After the matching, the mean difference for father's educational attainment was reduced from 0.64 to 0.12 and for mothers from 0.68 to 0.56. Consequently, educational attainment of the fathers in the matched dataset no longer differs, mothers in the ASD group are still less

TABLE 2 Availability of digital media in the home and frequency of use (children with ASD: $n = 15$, TD children: $n = 78$).

Digital media	Group	Available at home	Never used	Sometimes used	Often used	*U*	*z*	*p*
PC/Laptop	ASD	93.33% ($n = 14$)	42.86% ($n = 6$)	28.57% ($n = 4$)	28.57% ($n = 4$)	403	−1.55	0.122
	TD	98.72% ($n = 77$)	60% ($n = 45$)	30.67% ($n = 23$)	9.33% ($n = 7$)			
Tablet	ASD	93.33% ($n = 14$)	0% ($n = 0$)	50% ($n = 7$)	50% ($n = 7$)	416.5	−1.13	0.26
	TD	94.87% ($n = 74$)	12.5% ($n = 9$)	48.61% ($n = 35$)	38.89% ($n = 28$)			
Mobile phone	ASD	93.33% ($n = 14$)	35.71% ($n = 5$)	28.57% ($n = 4$)	35.71% ($n = 5$)	514	−0.21	0.834
	TD	100% ($n = 78$)	27.63% ($n = 21$)	50% ($n = 38$)	22.37% ($n = 17$)			
Game console	ASD	80% ($n = 12$)	41.67% ($n = 5$)	33.33% ($n = 4$)	25% ($n = 3$)	343	−0.93	0.351
	TD	65.39% ($n = 51$)	28.57% ($n = 14$)	34.69% ($n = 17$)	36.74% ($n = 18$)			
TV	ASD	93.33% ($n = 14$)	7.14% ($n = 1$)	35.71% ($n = 5$)	57.14% ($n = 8$)	453.5	−0.21	0.832
	TD	88.46% ($n = 69$)	7.46% ($n = 5$)	38.81% ($n = 26$)	53.73% ($n = 36$)			
Radio/Podcast/CD player/Audio-books	ASD	86.67% ($n = 13$)	16.67% ($n = 2$)	58.33% ($n = 7$)	25% ($n = 3$)	386	−0.02	0.982
	TD	92.31% ($n = 72$)	28.13% ($n = 18$)	35.94% ($n = 23$)	35.94% ($n = 23$)			
Digital assistants (e.g., Alexa)	ASD	46.67% ($n = 7$)	28.57% ($n = 2$)	14.29% ($n = 1$)	57.14% ($n = 4$)	87	−1.38	0.233*
	TD	48.72% ($n = 38$)	47.22% ($n = 17$)	27.78% ($n = 10$)	25% ($n = 9$)			
SMART toys (web-connected devices)	ASD	40% ($n = 6$)	16.67% ($n = 1$)	66.67% ($n = 4$)	16.67% ($n = 1$)	66	−1.81	0.069*
	TD	51.28% ($n = 40$)	67.57% ($n = 25$)	13.51% ($n = 5$)	18.92% ($n = 7$)			

Due to individual missing values, the sample size for the frequency of digital media use data differs in part from the sample size for the availability media devices in the home. The exact sample sizes can be found in the respective columns. *Exact significance ($n < 50$).

educated than in the control group (see Supplementary Table 2 for details). Analyses with the matched sample mainly confirm the group differences reported above. However, the use of smart toys was statistically significant in the Mann-Whitney-U-test with the matched dataset ($p = 0.007$) with a strong effect ($r = 0.55$). Boys with ASD ($M = 1$, $SD = 0.63$, $n = 6$) show higher exposure to SMART Toys than TD boys ($M = 0.29$, $SD = 0.73$, $n = 14$). Significant differences in media use for playing entertainment games with a higher mean score for children with ASD (ASD: $M = 1.67$, $SD = 0.49$, $n = 15$; TD: $M = 1.24$, $SD = 0.64$, $n = 29$) was also found in the matched dataset ($p = 0.043$). This effect was moderate ($r = 0.32$). On the parent self-report question about their children and media, a statistically significant difference in parents having difficulty limiting their child's media use was also found in the matched dataset ($U = 130$, $z = -2.20$, $p = 0.027$) with a moderate effect ($r = 0.33$). The mean score in the matched dataset was also higher for children with ASD ($M = 4.93$, $SD = 2.84$, $n = 15$) than for TD children ($M = 3.03$, $SD = 2.46$, $n = 29$). The detailed results of the analyses with the matched dataset can be found in the Supplementary Tables 3–5.

4. Discussion

4.1. Group differences

The present study aimed to evaluate media usage of school-aged boys with ASD in comparison to TD boys in Germany. Therefore, we assessed the availability of digital media in the home and frequency of digital media use as well as the individual reasons for using digital media and further media use issues. An additional question surveyed a possible concern of the parents regarding their children's media usage. Our findings show that over 86% of all the participating families had five or more than five different digital media available in the home. However, the number of digital media did not differ significantly between children with ASD and TD children. This shows the growth of digital media in society (e.g.,

TABLE 3 Reasons for using digital media as named by parents across both groups (children with ASD: $n = 15$, TD children: $n = 78$).

Child uses digital media to...	Group	Never used	Sometimes used	Often used	*U*	*z*	*p*
Play entertainment games	ASD $n = 15$	0% ($n = 0$)	33.33% ($n = 5$)	66.67% ($n = 10$)	337.5	−2.72	0.007
	TD $n = 76$	17.11% ($n = 13$)	51.32% ($n = 39$)	31.58% ($n = 24$)			
Play learning games	ASD $n = 14$	0% ($n = 0$)	64.29% ($n = 9$)	35.71% ($n = 5$)	441	−1.16	0.247
	TD $n = 75$	6.67% ($n = 5$)	69.33% ($n = 52$)	24% ($n = 18$)			
View photos	ASD $n = 13$	23.08% ($n = 3$)	46.15% ($n = 6$)	30.77% ($n = 4$)	442	−0.62	0.536
	TD $n = 75$	18.67% ($n = 14$)	66.67% ($n = 50$)	14.67% ($n = 11$)			
Take photos/videos	ASD $n = 13$	15.39% ($n = 2$)	53.85% ($n = 7$)	30.77% ($n = 4$)	351	−1.78	0.076
	TD $n = 74$	28.38% ($n = 21$)	62.16% ($n = 46$)	9.46% ($n = 7$)			
Listen to music/podcasts/ audiobooks	ASD $n = 15$	13.33% ($n = 2$)	33.33% ($n = 5$)	53.33% ($n = 8$)	643.5	−0.91	0.361
	TD $n = 76$	3.95% ($n = 3$)	32.9% ($n = 25$)	63.16% ($n = 48$)			
Watch movies/videos	ASD $n = 15$	6.67% ($n = 1$)	26.67% ($n = 4$)	66.67% ($n = 10$)	435	−1.59	0.113
	TD $n = 75$	0% ($n = 0$)	60% ($n = 45$)	40% ($n = 30$)			
Chat/interact with others	ASD $n = 15$	60% ($n = 9$)	33.33% ($n = 5$)	6.67% ($n = 1$)	488.5	−0.6	0.547
	TD $n = 71$	69.01% ($n = 49$)	23.94% ($n = 17$)	7.04% ($n = 5$)			

Spina et al., 2021) and its omnipresence in the life of school-aged children independently of ASD. Children in both groups have the device categories (1) PC/laptop, (2) tablet, (3) mobile phone, (4) game console, (5) TV, (6) radio/podcast/CD player/audiobook most often available at home. This is in line with the findings of the German KIM study (Feierabend et al., 2021). However, our hypothesis that boys with ASD use digital media at significantly higher rates as was reported previously (Dong et al., 2021; Krishnan et al., 2021) could not be confirmed both in unmatched as well as matched dataset. However, in the matched dataset, children with ASD used SMART Toys at higher rates than TD children.

The observed group difference in playing entertainment games revealed a small effect in the unmatched and a moderate effect in the matched dataset, indicating a robust finding. Thus, boys with ASD are more likely to use digital media to play entertainment games than TD boys. Possibly, children with ASD prefer spending time and enjoy themselves with digital media rather than with their peers. This interpretation is supported by findings that children with ASD prefer digital media as a leisure activity over other leisure activities such as outdoor play (Stiller and Mößle, 2018). Since the survey did not specifically ask for preferences of media time over social contact, no well-founded statements can be made about this at this point. Overall, we could not show that the reasons for using media differed between the two groups. Therefore, the second hypothesis, that the usage motives differ between boys with ASD and TD boys (e.g., Lane and Radesky, 2019) could not be confirmed either.

Nevertheless, the third hypothesis could only be confirmed in parents' perceptions of difficulty of restricting their child's media use. Both, in the unmatched and the matched dataset the effect was moderate, so this finding is also robust. The other group differences were not significant. One explanation could be the high standard deviations across both groups. For example, standard deviations are highest for reported immersion and are especially high in the ASD group. Since immersion is a mediated experience in which the sense of mediation vanishes and the experience feels as if being real (Biocca, 2002), it is difficult for parents to assess this. However, parents' report of confidence in using digital media, enjoyment of digital media, parents' ratings about their child's digital media behavior, immersion, and parents' perceptions of difficulty of restricting their child's media use is higher among the ASD group.

Overall, we have no indication that ASD children use digital media more frequently and for different reasons than TD children,

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TABLE 4 Parents perception of their children media usage across both groups (children with ASD: $n = 15$, TD children: $n = 78$).

Parents perception …	Group	*M (SD)*	Total: *M (SD)*	*U*	*z*	*p*
Of child's confidence in using digital media	ASD	7 (2.45)	6.45 (2.16)	492	−0.98	0.329
	TD	6.45 (2.07)				
Of child's enjoyment of digital media usage	ASD	9.53 (0.64)	8.81 (1.75)	468.5	−1.32	0.189
	TD	8.81 (1.75)				
Of child's immersion during digital media use	ASD	7.33 (3.29)	7.02 (2.72)	510	−0.72	0.472
	TD*	7.1 (2.57)				
That their child spends too much time with digital media	ASD	6.2 (2.46)	5.32 (2.61)	459.5	−1.32	0.188
	TD	5.21 (2.65)				
Of difficulty in limiting their child digital media usage	ASD	4.93 (2.84)	2.96 (2.39)	285	−3.20	0.001
	TD*	2.57 (2.11)				

The variables were assessed on a 10-point scale. *$n = 77$.

TABLE 5 Spearman's correlations.

Variable		1	2	3	4
1. Assessing the child's confidence in using digital media	*Spearman's Rho*				
	p-value				
	N				
2. Enjoyment of digital media usage	*Spearman's Rho*	0.41			
	p-value	**<0.001**			
	N	96			
3. Immersion	*Spearman's Rho*	0.04	0.39		
	p-value	0.712	**<0.001**		
	N	95	95		
4. Belief that their child spends too much time using digital media	*Spearman's Rho*	0.22	0.34	0.28	
	p-value	**0.028**	**<0.001**	**0.006**	
	N	96	96	95	
5. Difficulties limiting their child's media usage	*Spearman's Rho*	0.06	0.1	0.11	0.51
	p-value	0.575	0.348	0.315	**<0.001**
	N	95	95	94	95

The variables were assessed on a 10-point scale. Significant *p*-values are in bold.

except for playing entertainment games. Furthermore, our results also show no group differences for parents' reports regarding their child's media usage, except for parents' perceived difficulty of restricting it.

4.2. Study limitations and future research desiderates

The main limitation of the current investigation results from the difference in sample sizes–including the small size of the ASD group–and the partly large reported standardized mean differences. However, children with ASD are a vulnerable target group with a rather low prevalence: approximately 1 in 100 children worldwide has ASD (Zeidan et al., 2022). It is therefore common that recruitment of children with ASD is more difficult than that of TD children. Nevertheless, the dataset should be extended. So far, our data provide a first insight into the use of digital media in school-aged boys in Germany. The fact that there were no group differences for media exposure and reasons for digital media use, may also be a result of the chosen age range (6 to 11 years). With age, the preferences of media and consumption evolve (Feierabend

et al., 2021). Although the age range in our study was with 6 to 11 years rather large, small sample size did not allow for separating age subgroups. The sample consist of primary school children only, but we do not know about relevant differences between younger and older children. Other studies on children media usage, however, find the main age gap appearing after primary education in Germany around the age of 11 years (Ritterfeld and Lüke, 2021).

Parents in the TD group are better educated than parents in the ASD group. Recruitment did not particularly emphasize SES. As lower SES is often associated with higher media use time or possibly problematic use behavior (Nikken and Opree, 2018) group differences might at first glance be attributed to SES. However, as parents of children with ASD are also reporting higher concerns regarding and difficulties in limiting their child's media consumption, SES does not seem a valid explanation. This interpretation is confirmed by the analyses in which age and parents' educational attainment was controlled.

Another limitation lies in the method chosen. In the current investigation, we surveyed children's behavior through parents' reporting. Although a study by Wood et al. (2019) shows that parents' and children's judgments of media use were similar, parents may have had a different threshold for the questions and operationalize the values differently for themselves. This may explain some of the high standard deviations. Further studies should also collect data on how parents operationalize too much time with digital media and what they consider to be the threshold for limiting exposure. In addition, when asking whether the child spends too much time with digital media, it should be taken into account that the response might be different for parents who strongly limit their children's media use than for parents without such intention. Conversely, it could be that it is precisely those parents who apply a limitation of media time who are particularly concerned about their children's media use but did not express this due to the item wording in the present study. This could be supported by the correlation between spending too much time with digital media and difficulties in limiting digital media usage. Thus, the items may need to be expanded to include whether and to what extent the child demands time with digital media and what restrictions exist in the individual families. Active demand for the use of digital media could also be considered as an additional variable. In this context, a possible relationship between the frequency of digital media use and the difficulty of restricting should be examined in further studies. In addition, further research should explore the parent's attitudes toward digital media and ASD, e.g., when parents believe that media are the only entertainment for their child that they can provide for him or her. Parents may generally be concerned that children with or without ASD will develop problematic behaviors because of media use. For example, a study by Mazurek and Engelhardt (2013) examined the correlation between video game use and problematic behavior in boys with ASD aged 8 to 18 years. One finding was that problematic game use and role-playing game genre were significant predictors of oppositional behavior, even after controlling for age and time spent playing video games (Mazurek and Engelhardt, 2013). However, this is also debated for (apparently) TD adolescents who are the subject of media attention due to a school rampage.

Taken together and in line with the extensive literature overview, our results suggest that digital media already play an important role in everyday lives of children with ASD. Especially with the increasing use of digital media as well as the development of new media formats, media usage and effects should be continuously explored for children with ASD. Special emphasis should be given to identify formats than can support their needs and account for their disorder-driven barriers. Formats that rather enhance their symptoms should be constrained. Hereby, age is an important factor to be considered. For example, a recent study by Krishnan et al. (2021) shows that children with ASD were exposed to digital media at an earlier age compared to TD children. But it remains unclear whether this tendency is useful or harmful and what the parent's reasons for this decision might be.

4.3. Implications for digital participation in individuals with ASD

In today's world, digital media are an essential factor for social participation as even social communication is often mediated. As Glumbić et al. (2022) recently stated, the great potential of digital participation in the daily lives of people especially with ASD is evident. It is important to emphasize that individuals with ASD are not generally lacking interest in social contact, but rather feel – or are informed subliminally by their counterpart – an inability to adhere to social conventions of exchange (Begeer et al., 2008). The question arises as to what extent this can be achieved more easily in the digital space, and whether digital participation could thus function as a substitute for real-world contacts.

Social-communicative abnormalities are a core aspect of ASD-associated symptomatology. Since corresponding interactional deficits can restrict the children's participation, two possible consequences could arise for the aspect of digital participation: on the one hand, it is conceivable that the corresponding pragmatic deficits could also show up in the digital space and result in comparable interactional restrictions and possibly in exclusion or negative communication experiences. At the same time, however, some research indicates that the children find communication easier or even more successful in the digital setting, when the direct pressure of face-to-face contact is removed (Pinchevski and Peters, 2016). Further investigation of online communication by pragmatically impaired children would be desirable and could potentially have societal and even educational implications. At the same time, digital space for children should not be lightly equated with a safe space, as phenomena such as cyberbullying are unfortunately widespread.

In the introduction above, we highlighted great potential of new media for diagnostics, intervention, and education for individuals with ASD. However, we are just about to explore, develop and capitalize it. For example, mediated social interaction as provided by an avatar may not only be a suitable and economic approach in clinical or educational settings, but may even cater to the specific needs of children with ASD in overcoming typical barriers in face-to-face-interactions while communicating with others. According to the World Health Organization's International Classification of Functioning, Disability, and Health (ICF), health status (disability), body function and structure, contextual factors, and participation

are interrelated. Technologies as well as the competence in dealing with digital media as context factors play an important role in the lives of individuals with ASD (Glumbić et al., 2022). For example, Schutt (2018) demonstrated that social communication can be facilitated through digital participation. The Online Lab program applied in the study by Schutt (2018) was designed for children and adolescents aged 10 to 16 years with ASD who have trouble interacting with others, at worst with the consequence of social isolation. However, the effects of the program on the development of social and technical skills were mixed. Although young people with ASD enjoyed participating in this online program and they reported that it strengthened their relationships with others, only four out of seven participants reported improved social participation in daily life, both within and through the program. The study offers some encouragement for improving (everyday) social participation using digital tools but points to the necessity of further research. Specifically, the potential of gamification for motivation, immersion, engagement, and intervention needs to be addressed (Atherton and Cross, 2021). In addition, mobile applications have been shown to be helpful to participate for children with ASD (Wojciechowski and Al-Musawi, 2017) since they can even facilitate communication in everyday activities. For example, the mobile assistance system "Let's Play" aimed to support children with ASD in their process of learning the pronunciation and meaning of new words embedded in everyday communication (Wojciechowski and Al-Musawi, 2017). A preliminary evaluation with two children by the authors raises some hope for more efficient vocabulary learning compared to a corresponding period without the support of an assistive application (Wojciechowski and Al-Musawi, 2017).

Summarized, the presented small study provides an initial insight into the media use of boys with ASD in Germany while allowing a view into the wide field of the importance of digital media in the life of children with ASD. Our research supports findings that digital media are highly attractive to children with ASD, that they use digital media frequently, and are confident in their usage. There is no question that new media are an integral part of the daily lives of children with ASD, as well as concerning educational services, interventions, and screenings. As such, digital media and the digital environment have the potential to enhance the social inclusion of people with ASD.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

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

Author contributions

LP, IN, and UR developed the concept for the present study. The literature review and most of the writing were done by LP. IN and LP collected the data. All results were computed by LP and the paper was revised by IN and UR. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fcomm.2023.1224585/full#supplementary-material

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Appendix B: Study II

Pliska, L., Kunina-Habenicht, O., & Ritterfeld, U. (2025a). Media use among children with ASD: Perspectives and concerns of parents. *PLOS One, 20(10),* e0332504. https://doi.org/10.1371/journal.pone.0332504

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RESEARCH ARTICLE

Media use among children with ASD: Perspectives and concerns of parents

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Abstract

Digital media is a significant part of daily life for both adults and children, raising concerns among parents about its impact on child development, particularly for those with autism spectrum disorder (ASD). This study explores the differing perspectives and concerns of parents with and without ASD regarding their children's media use. A total of 117 parents of children with ASD and 58 parents of typically developing (TD) children participated in an online survey. The study employed group comparisons, correlations, and hierarchical regressions. Results show that parents of children with ASD expressed greater concern about media use compared to TD parents, especially regarding potential negative effects on health and behavior. However, these concerns did not extend to child development or intensification of ASD symptoms. Key predictors of parental concern included challenges in limiting media use, perceptions of media preference and addiction, and children's ability to cope without media. While parents of children with ASD have notable concerns about media use, these are not excessively pronounced compared to TD parents. Many report allowing digital media as a means for self-regulation in their children. Future research should also examine positive aspects of digital media usage as potential influencing factors.

Introduction

Children today are growing up with media devices as a matter of course [1,2]. The results of a representative study on media use among 6–13-year-olds in Germany in 2022 show that children are growing up with a broad media repertoire [3]. Almost all households have a TV, smartphone, computer/laptop, and internet access. Fifty-five percent own a tablet, and 51% own a game console. According to parents, children themselves own relatively few devices, but this increases with age. For example, only 9% of 6–7-year-olds own a smartphone, whereas 27% of 8–9-year-olds and more than half (58%) of 10–11-year-olds own a smartphone [3].

As the use of digital technologies continues to grow, the duration of children's use has become an important issue for concern [4], especially for children with autism

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spectrum disorder (ASD). This is because ASD is a neurodevelopmental disorder (DSM-5; [5]), and screens are assumed to have a significant impact on children's neurological development [6]. In addition, people with ASD tend to spend more time in front of screens each day and are at greater risk for screen addiction than people without ASD are [7]. Studies have consistently shown that screen-based media is a preferred leisure activity for children and adolescents with ASD but have reported mixed results regarding whether children with ASD spend more time with screen-based media compared to children without ASD (see the systematic review by Stiller & Mößle [8]). A study by Dong et al. [9] showed that children with ASD spend significantly more time in front of screens (3.34 ± 2.64 h) than typically developing (TD) children (0.91 ± 0.93 h). Other studies also have shown that children with ASD are exposed to more screen time and that this exposure starts at a younger age than TD children [10–12]. These group differences can be found not only in comparison with TD individuals but also in comparison with other clinical groups such as as delayed language development [11].

However, several studies have also reported contradictory results. For example, Mosa et al. [6] reported no significant differences between children with and without ASD in terms of early screen exposure. Additionally, a U.S. national survey of parents of school-aged children (aged 6–17) revealed no difference in screen time between children with and without ASD (TD: 3.21 hours per day; ASD: 3.46 hours per day), where both groups had high screen use [13]. In Germany, Pliska et al. [14] also reported no differences in media use between children (aged 6–11) with and without ASD. Additionally, no differences were found in the frequency of media use or the reasons for use. However, parents of children with ASD reported greater difficulty in limiting their child's media use than did parents of TD children [14]. Limiting screen time is the most common strategy for regulating children's use of digital technology [4]. Kuo et al. [15] showed that parents use similar strategies for controlling screen time for adolescents with ASD as they do for their siblings without ASD but more often use more restrictive strategies. Restrictive control is associated with parental concerns about the duration of media use [15]. Overall, parental concerns about media use are significantly related to mediation strategies for adolescents with ASD [15].

Parents' beliefs about their children's media use

Each parent has beliefs (convictions and personal opinions) about children's media use, which influence how children interact with and grow up with media [3,16]. They have beliefs about the benefits or harms of media or the age at which children should use it [16]. Overall, children spend more time with electronic devices during sensitive developmental periods, such as the first years of life [17]. Some parents are concerned about their young child's media use [18] while others are not particularly concerned [19]. As a result of being worried, some parents have established rules for the whole family, and others have established rules only for their young children [4]. A qualitative study by Bartau-Rojas et al. [20] indicated that parents share a pessimistic (70.55%) rather than an optimistic (29.45%) attitude toward internet use among

primary school children. Some parents are concerned about excessive online time, the ability to handle content, negative effects on learning and academic performance, physical development, social skills and peer interaction, child well-being [20], and potential risks and security threats in virtual environments [21]. In addition, many parents are worried about losing control over the online behavior of their children [20]. Other potential negative effects highlighted by parents include health, psychological development, family relationships, and the security of personal information when social media is used [21]. For example, one negative consequence of screen media consumption is obesity, although there is also indication that the usage of interactive media, such as exergames, can even prevent or reduce obesity [22]. Many parents reported that conflicts with their children about technology use negatively affected their relationships [21]. In this context, a panel study by Matthes et al. [23] revealed that excessive smartphone use by parents was associated with a loss of control over children's smartphone use, which in turn led to conflicts over smartphone use within the family over time. Overall, parents with a lower education degree tend to have more negative attitudes toward technology than parents with a bachelor's degree [21]. These negative attitudes were moderate and stemmed from concerns that excessive use could lead to their children becoming dependent on technology or being exposed to inappropriate content [21]. However, parents also have positive views about the impact of media usage, for example, on entertainment, communication, learning, and skill development [20]. In addition, more positive parental beliefs about screen media are significantly associated with intensive sharing and greater consumption of media content perceived as educational [24].

Common concerns of parents can be exacerbated when their child is diagnosed with ASD [25]. Compared with parents of TD individuals, parents of individuals with ASD are significantly more likely to report that the use of electronic devices negatively impacts their children's behavior [26]. Laurie et al. [25] found that parents of children with ASD had concerns about technology use, especially the amount of time the device was used and the social consequences. Parents' reported concerns about the use of technology by their children with ASD were related to a longer duration of use. However, it is possible that parents who are very concerned overestimate the time, whereas parents who are less concerned underestimate it [25]. Additionally, children with ASD exhibit clinical characteristics that can contribute to problematic media use, such as deficits in social communication, a tendency to play alone, restricted interests, sensory differences, and difficulties with executive function [27]. They are attracted to interactive media and digital games for longer periods of time because they satisfy their sensory needs and allow them to avoid unpredictable social stimuli without complex control mechanisms [27]. The link between problematic screen use and ASD is likely because screen media meet both sensory stimulation and solitary activity needs, which are both linked to ASD [27,28]. Devices (e.g., smartphones) are often used by children with ASD to provide comfort and help them deal with social overstimulation [29]. Non-functional use of technology, such as repeatedly watching the same video, could play an important role in the lives of children with ASD, for example, as a means of relaxation [25]. New media opens new opportunities for people with ASD, as the internet provides a living space free from the stress of face-to-face encounters [30]. Additionally, individuals with ASD can modify their communication environment via technology, for example, by using asynchronous options and reducing the use of sensory stimuli to meet different social needs [31]. Shane and Albert [32] show that, when given more free time, such as on weekends, children with ASD tended to engage in media interaction instead of other play activities, in comparison to when they had less free time, such as during the week. Parents also report significant verbal and physical imitation during and after electronic screen media use [32]. Media is often seen as a tool to improve communication skills of children with ASD [33]. In addition, more than half of the parents reported positive effects of media use on their children's emotional regulation. A significant correlation was found between time spent in front of television or the internet and the ability to cope with stress [33]. However, parents use media in part to regulate their child's distress [34] and manage their child's difficult emotions, especially if the child has a more challenging temperament [35]. The results of an analysis of media use for emotion regulation in young children (2–3 years) revealed that higher levels of media emotion regulation were associated with more problematic media use and more extreme emotions when the media was removed [35].

Overall, the relationships among parental beliefs, total screen time, use for behavioral regulation, and limit setting depend on parental stress levels and, to a lesser extent, parental media skills [24]. In other words, the relationships between parental beliefs and screen media use practices are less pronounced for parents with lower media skills and higher stress levels [24].

Screen time and ASD

Recently, research on the effects of screen time on children with ASD has increased due to a growing interest in the causes of ASD symptoms and therapeutic approaches that incorporate technology and electronic devices [36]. Alrahili et al. [17] found a significant correlation between digital device use and deficits in the development of social skills and symptoms indicative of ASD. Research indicates that greater screen exposure in children is associated with a greater likelihood of an ASD diagnosis [7,37], with those in the highest exposure group having a 97% greater chance of a diagnosis than those in the lowest exposure group [7]. Digital media use before 21 months of age was associated with ASD risk (sensitivity of 71% and specificity of 72%), and the risk increased when mothers spent less than 6.5 hours per day with their child [12]. Hill et al. [38] showed that children who were later diagnosed with ASD or attention-deficit/hyperactivity disorder (ADHD) had, on average, more than twice as much screen time as the comparison group, and the ASD and ADHD groups had similar screen time. Increased screen time at 18 months of age was significantly associated with greater symptoms of ASD and ADHD, as well as lower developmental scores at 3 to 5 years of age. The authors noted that increased screen time, along with the challenges associated with ASD and ADHD, may have a cumulative effect on development. However, they emphasize that their study cannot determine whether increased screen time at an earlier stage of development leads to increased neurodevelopmental symptoms or is secondary to other factors associated with developmental trajectories and behavioral phenotypes [38].

A systematic review and meta-analysis of the association between screen time and ASD suggests that the purported link is not well supported by the existing literature, although the observed effects are most pronounced in children [39]. However, the direct effect of excessive screen time during early childhood on the increased risk of ASD remains inconclusive, with some studies reporting an association (e.g., [11,40]), whereas others finding no association (e.g., [13]).

Virtual autism

The concept of “virtual autism” was first introduced by Marius Zamfir, who hypothesized that daily screen time in excess of four hours or more could induce sensory-motor and socio-emotional deprivation in children 0–3 years of age, similar to the behaviors of children with ASD [41]. Several studies have confirmed the presence of ASD-like symptoms in young children overexposed to electronic screens [42]. For example, research indicates that excessive screen time in young children is associated with developmental and behavioral issues resembling ASD, including language delays, social challenges, emotional instability, and attention problems [43–45]. In addition, a study by Al Moussawi et al. [46] highlighted the strong association between earlier and longer screen use and the development of ASD-like behaviors, with boys showing greater susceptibility to ASD-like traits. A single-case-study [43] and a cross-sectional study [44] further support that longer screen time correlates with developmental delays and ASD-like behaviors, especially when it exceeds two hours daily. Furthermore, a cohort study by Heffler et al. [40] revealed that early screen exposure and less interactive play at 12 months were linked to more ASD-like symptoms at age two, although not necessarily increasing ASD risk. Children with ASD tend to spend more time on screens, with longer screen time being associated with more severe ASD symptoms (particularly sensory symptoms) and more significant developmental delays [9]. This is particularly the case for children with ASD who spend longer times in front of a screen and are younger [9]. An intervention by Heffler et al. [47] demonstrated that replacing screen time with parent-child social engagement significantly reduced screen use from 5.6 hours to 5 minutes daily and improved core ASD symptoms and parental distress over six months. Similarly, a study by Nisar et al. [48] suggested that ASD-like symptoms through excessive screen time in young children are reversed with early intervention. Overall,

reducing screen time and enhancing parent-child interaction are essential strategies to mitigate developmental and behavioral issues linked to excessive digital media use in early childhood [43,49].

Although children with virtual autism exhibit behaviors similar to those of children with ASD, distinguishing between the two is important [50]. ASD is a neurodevelopmental disorder that involves genetic, biological, and environmental influences and is typically diagnosed on the basis of developmental markers, whereas virtual autism, which is not an official diagnosis [51], appears to be due primarily to environmental factors, particularly the overuse of digital technologies during critical developmental periods [50]. Studies by Chakraborty [50] and Rakshit and Biswas [52] suggest that virtual autism may be reversed by reducing screen time and increasing participation in non-media activities, whereas ASD requires long-term interventions. The use of terms such as "virtual autism" remains therefore controversial. Critics argue that labeling developmental problems caused by excessive screen use as "autism" is misleading and may lead to a misunderstanding of ASD [42].

Study aims and research question

The literature provides contradictory evidence regarding parents' concerns about their children's media use (see 'Parents' beliefs about their children's media use'). Some parents are concerned [18] while others are not [19]. In addition, parents' concerns may intensify if their child is diagnosed with ASD [25]. However, contrasting results can also be found among parents of children with ASD (see 'Parents' beliefs about their children's media use'). On the one hand, studies indicate that parents of children with ASD are concerned about the potential negative effects of media use on their children's behavior [26]. However, other studies highlight the positive impact of media on children with ASD [33]. Overall, it is unclear whether parents' concerns about media use differ depending on whether or not their child has ASD. One of the aims of this study is therefore to investigate whether the concerns of parents with children with and without ASD differ in relation to their children's media use. The research question in this regard is: Do parents' attitudes and concerns differ between children with and without ASD?

Additionally, contradictory results have been reported regarding the potential association between excessive screen time during early childhood and an increased risk of ASD (see 'Screen time and ASD'). Furthermore, it has been shown that expressive media exposure can cause ASD-like symptoms (see 'Virtual autism'). Therefore, the study also aims to examine, whether parents' attitudes and concerns differ regarding media consumption and ASD-like symptoms or ASD development.

Method

Participants

In accordance with the Declaration of Helsinki, a positive ethics vote by the Ethics Committee, Department of Rehabilitation Sciences, TU Dortmund University (GEKTUDO-2024–54) was issued. From November 11, 2024, to May 15, 2025, a total of 526 individuals accessed the online parent questionnaire and provided written informed consent, mainly through autism therapy centers, self-help groups, parent groups, social media, and private contacts in Germany. However, 319 forms were discarded because they were incomplete. Of the remaining 207 questionnaires, 27 questionnaires were discarded to reduce the dataset to families with children who were developing typically (no diagnosis or suspicion) or had already been diagnosed with ASD. Five more questionnaires were removed because the children were outside the 6–11 age range. The final dataset consists of 175 completed questionnaires (dropout rate of 66.7%). Of those 117 were assigned to the ASD group and 58 to the TD group.

On average, the children in the ASD group ($n = 117$) were 106.15 months (8;10 years) old ($SD = 19.7$; age range 6;0–11;09). The sex ratio was 4:1 (93 males and 24 females), which is consistent with the prevalence of ASD [53–55], although a ratio of 3:1 is now assumed [56]. Among the 117 children, 35 had only an ASD diagnosis, while 66 also had comorbid AD(H)D. Other comorbidities included intellectual disability, language development disorder, dyslexia, learning

disability, and dyscalculia. At an age-appropriate level, communication with others is possible for 88 children, communication with others is possible only to a limited extent for 24 children, and 4 children have no verbal language. In the ASD group, 25 children had no siblings, 55 had one sibling, 30 had two siblings, and seven had three siblings. On average, the children in the TD group ($n = 58$) were 104.84 months (8;08 years) old ($SD = 16.29$; age range 6;03–11;08). The TD group had a sex ratio of 3:2 (36 males and 22 females). Despite the different sex ratios, the two groups can be used for comparison since no gender-specific differences in media usage were found by MacMullin et al. [26]. At an age-appropriate level, communication with others is possible for 57 children, and communication with others is possible only to a limited extent for one child. In the TD group, 12 children had no siblings, 26 children had one sibling, 11 children had two siblings, six children had three siblings, and three children had four to six siblings. For both groups, the questionnaire was predominantly completed by mothers (see Table 1).

Measures

An ad hoc online survey for parents was used to collect data on children's media usage and parents' attitudes and concerns about their children's media usage. Items from different questionnaires were tailored to the research question for this purpose. The final questionnaire can be found in the supporting information, S1 and S2 Appendix. The survey included items about the types of media available at home, the frequency and duration of children's media usage, and the reasons for using digital media. Wood et al. [57] showed that parents and children generally agreed on their responses to media exposure, allowing parental responses to be used. Parents were asked to provide information about how much time their children spend with digital media during the week and on weekends. They were asked to use the following categories: "Never = 0", "Up to 30 minutes = 1", "One hour to two hours = 2", "Two hours to four hours = 3", and "More than four hours = 4". Parents were also asked to state the maximum number of minutes or hours their child should spend with digital media during the week and on weekends. For parents who specified time periods rather than specific times, the mean was calculated. Parents were asked to rate various statements about their child's use of digital media in everyday

Table 1. Information about the person who completed the questionnaire.

Information about the person who completed the questionnaire	ASD ($n = 115$; missing = 2)	TD ($n = 57$; missing = 1)
The questionnaire was completed by	• Mother: 109 • Father: 4 • Other person: 2	• Mother: 45 • Father: 10 • Other person: 2
Age	$M = 39.88$ ($SD = 5.4$) Range: 27–52 years	$M = 41.12$ ($SD = 5.85$) Range: 25–57 years
Diagnoses	• No: 68 • Yes: 47 - AD(H)D - ASD - ASD and AD(H)D	• No: 55 • Yes: 2 - AD(H)D
Highest level of education: Person 1 (i.e., mother)[1]	• Less than high school degree: 38 • High school degree: 37 • College degree and more: 39	• Less than high school degree: 4 • High school degree: 14 • College degree and more: 38
Highest level of education: Person 2 (i.e., father)[2]	• Less than high school degree: 47 • High school degree: 23 • College degree and more: 36	• Less than high school degree: 12 • High school degree: 10 • College degree and more: 35

[1]The person who answered the questionnaire (i.e. mother).

[2]Information provided by the person who completed the questionnaire about the highest level of education of another person/ caregiver (i.e. father).

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life via a Likert scale ranging from 1 (“Never applies”) to 10 (“Almost always applies”). The items on the child’s use of digital media in everyday life were summarized into three subscales (see supporting information, S3 Appendix): preference for digital media and media addiction (15 items, α = .9); media skills (4 items, α = .56); and restrictions and challenges in regulating media use (5 items, α = .82). High scores on the media addiction subscale indicate greater dependence on media. High scores on the media skills subscale indicate greater media skills, whereas high scores on the restrictions and challenges in regulating media use subscale indicate fewer restrictions and greater difficulty in implementing them. Finally, they were asked to rate statements about their thoughts and concerns regarding their child’s media use on a scale from 1 (“Disagree”) to 10 (“Agree completely”). The items regarding parents’ concerns about their children’s media use were summarized into five subscales (see supporting information, S3 Appendix): media addiction (3 items, α = .82); loss of connection to the real world (4 items, α = .89); negative effects on health and behavior (7 items, α = .85); worries about online dangers, loss of control, and parental media skills (8 items, α = .84); and no support as a reason for worries (2 items, α = .78). Here, higher values indicate greater worry. The concern scale without ‘No support as a reason for worry’ subscale, comprising 22 items, has a Cronbach’s alpha of.95. Additionally, the two items related to concerns about media use and ASD symptoms were combined into a subscale with a Cronbach’s alpha of.67. To account for missing values, the subscales were formed based on the mean value.

Data analysis

Descriptive and statistical data analysis was carried out via R version 4.4.2 [58] (see R code in supporting information, S4 Appendix). Group comparisons, correlations, and hierarchical regressions were performed to address the research question. The ‘psych’ and ‘car’ packages were used for descriptive data and to check the assumptions. The Shapiro test was used to calculate the normal distribution of the variables, and the Levene test was used to calculate the variance homogeneity. If these prerequisites were violated, the Mann-Whitney *U*-test was used as a non-parametric alternative for group comparisons and Spearman’s correlation, both of which were corrected via the Bonferroni method. For significant results in the Mann-Whitney *U*-test, the effect sizes (rank correlation coefficient = *r*) were also calculated. A rank correlation coefficient of $r = .10$, $r = .30$, and $r = .50$ indicates a small, moderate, and strong effect [59]. In hierarchical regression, parents’ worries were examined in relation to their child’s media use. Cohen’s f^2 was also calculated as an effect size. According to the guidelines by Cohen [59], $f^2 \geq 0.02$, $f^2 \geq 0.15$, and $f^2 \geq 0.35$ represent small, medium, and large effect sizes. The first model included the control variables of the child’s impairment, age, and gender. The second model included the variable of difficulties in restricting media consumption, and the third model included the parents’ perceptions of their child’s media preference and addiction. The fourth model adds the number of hours that children can cope without media without experiencing problems, and the final model adds the maximum daily media time that parents consider appropriate for their child. Prior to the hierarchical regression analysis, a dataset containing only parents’ worries and predictors was created, and all datasets with missing values were discarded to enable the analyses. The significance level was set at 5%.

Results

There were no significant differences in terms of the number of digital devices available in the household ($U = 3124.5$, $z = -0.88$, $p\text{-}adj = 1$) and the frequency of digital media use ($U = 2795.5$, $z = -1.82$, $p\text{-}adj = 1$) between the ASD group (number of digital devices ($n = 117$): $Md = 7$; frequency ($n = 116$): $M = 1.58$, $SD = 0.43$) and the TD group (number of digital devices ($n = 58$): $Md = 7$; frequency ($n = 58$): $M = 1.47$, $SD = 0.49$) (for more information on media use, see supporting information, S1-S10 Tables). The maximum amount of time that parents consider to be appropriate for media use per day differed significantly between the ASD and TD groups, both during the week ($U = 4713.5$, $z = -4.99$, $p\text{-}adj < .001$, $r = .73$) and during weekends including holidays ($U = 4292$, $z = -4.18$, $p\text{-}adj < .001$, $r = .7$). Parents of children with ASD considered 120.57 minutes ($SD = 81.93$, $n = 115$) during the week and 182.54 minutes ($SD = 92.69$, $n = 112$) on weekends to be the maximum appropriate amount of time. The parents of TD children considered 63.75 minutes ($SD = 33.05$; $n = 56$) during

the week and 122.27 minutes ($SD = 58.1$; $n = 55$) on weekends to be the maximum appropriate duration. As the maximum time considered appropriate for children's media use differed significantly between weekdays and weekends ($U = 7705.5$, $z = -7.4$, $p\text{-}adj < .001$, $r = .27$), the mean of the two values was calculated for further analysis. Similarly, the mean maximum acceptable media use time differed significantly between the ASD and TD groups ($U = 4475$, $z = -4.73$, $p\text{-}adj < .001$, $r = .73$). On average, parents of children with ASD considered 150.76 minutes ($SD = 81.23$; $n = 112$; range = 30−390) appropriate, whereas parents of TD children considered 93.05 minutes ($SD = 44$; $n = 55$; range = 30–180) appropriate. There is also a significant difference in how often parents give their children digital devices to help self-regulate when they are unwell ($U = 4571$, $z = -4.24$, $p\text{-}adj < .001$, $r = .69$; ASD: $M = 1.77$, $SD = 1.02$, $n = 116$; TD: $M = 1.05$, $SD = 0.89$, $n = 57$). Overall, parents' assessments of how long their children can cope without using media in everyday life differed between the two groups ($U = 1884$, $z = -4.96$, $p\text{-}adj < .001$, $r = .28$). Among the 117 parents of children with ASD, 51.28% ($n = 60$) reported that their child could manage a whole day or more without using media. Among the 58 parents of TD children, 81.04% ($n = 47$) said the same. For more information, see supporting information, S11-S12 Tables.

There was a significant difference in parents' assessment of their children's preference for and addiction to digital media in everyday life between the groups ($U = 4893.5$, $z = -5.01$, $p\text{-}adj < .001$, $r = .73$; ASD: $M = 4.88$, $SD = 1.81$, $n = 115$; TD: $M = 3.45$, $SD = 1.50$, $n = 58$). The two groups also differ in terms of the child's and parent's media skills ($U = 4348$, $z = -3.37$, $p\text{-}adj = .013$, $r = .65$; ASD: $M = 5.87$, $SD = 1.71$, $n = 116$; TD: $M = 4.95$, $SD = 1.39$, $n = 57$). Additionally, the two groups differed significantly in terms of parents' assessments of restrictions and challenges in regulating media use ($U = 5248.5$, $z = -6.42$, $p\text{-}adj < .001$, $r = .8$; ASD: $M = 4.01$, $SD = 2.17$, $n = 115$; TD: $M = 2.09$, $SD = 1.31$, $n = 57$). Furthermore, there were statistically significant differences in parents' concerns about media addiction between the two groups ($U = 4743.5$, $z = -4.29$, $p\text{-}adj < .001$, $r = .7$; ASD: $M = 5.52$, $SD = 2.68$, $n = 117$; TD: $M = 3.64$, $SD = 2.64$, $n = 58$). Concerns about their children losing their real-world experience through media use were not statistically significant ($U = 4203$, $z = -2.8$, $p\text{-}adj = .086$; ASD: $M = 3.97$, $SD = 2.62$, $n = 115$; TD: $M = 2.93$, $SD = 2.45$, $n = 58$). A significant difference was found in the concerns of parents in both groups regarding the negative effects of media use on health and behavior ($U = 3683.5$, $z = -3.19$, $p\text{-}adj = .025$, $r = .65$; ASD: $M = 2.9$, $SD = 1.84$, $n = 99$; TD: $M = 2.15$, $SD = 1.74$, $n = 57$). Overall, the concerns of parents with children with ASD differ significantly from those of parents with TD children ($U = 3647$, $z = -3.3$, $p\text{-}adj = .016$, $r = .66$; ASD: $M = 3.49$, $SD = 1.76$, $n = 97$; TD: $M = 2.69$, $SD = 1.84$, $n = 57$). However, parents' concerns about their children's media use are not affected by the child's gender ($U = 2659$, $z = -1.24$, $p\text{-}adj = 1$; boys: $M = 3.28$, $SD = 1.82$, $n = 112$; girls: $M = 2.95$, $SD = 1.83$, $n = 42$). No differences were found between the two groups in terms of parents' concerns in relation to media use and ASD symptoms ($U = 3348$, $z = -2.04$, $p\text{-}adj = .697$; ASD: $M = 1.87$, $SD = 1.86$, $n = 101$; TD: $M = 1.44$, $SD = 1.51$, $n = 58$).

Parents' concerns about their child's media addiction were significantly correlated with their perception of a preference for digital media and addiction ($r_s = 0.73$, $p\text{-}adj < .001$), the challenges of limiting media use ($r_s = 0.61$, $p\text{-}adj < .001$), and their assessment of how many hours their child can cope without media without experiencing problems ($r_s = -0.53$, $p\text{-}adj < .001$). Parents' concerns about the negative effects of digital media on behavior and health were significantly correlated with their perceptions of a preference for and addiction to digital media ($r_s = 0.58$, $p\text{-}adj < .001$). The maximum daily screen time that parents consider appropriate correlates significantly with the problems of restricting media use ($r_s = 0.42$, $p\text{-}adj < .001$), their assessment of how many hours their child can cope without media without experiencing problems ($r_s = -0.37$, $p\text{-}adj < .001$), and the child's age ($r_s = 0.31$, $p\text{-}adj < .001$). However, there was no significant correlation between parents' concerns and their child's age ($r_s = 0.06$, $p\text{-}adj = 1$) and the maximum daily screen time that parents considered appropriate ($r_s = 0.18$, $p\text{-}adj = .372$). A significant correlation was found between parents' concerns and their assessment of how long the child can cope without digital media without experiencing problems ($r_s = -0.55$, $p\text{-}adj < .001$), parents' perception of a preference for digital media and addiction ($r_s = 0.68$, $p\text{-}adj < .001$), and challenges limiting media use ($r_s = 0.56$, $p\text{-}adj < .001$).

The control variables of impairment, the child's age and gender were used in a hierarchical regression analysis to examine the influence of various predictors on parents' concerns regarding their child's media use. The impairment

variable was significant ($p = .036$). However, age and gender of the child had no significant influence ($p > .05$). The model incorporating the control variables was not significant ($F(3,143) = 1.933$, $p = .127$, *adjusted* $R^2 = 0.02$, $f^2 = .02$). Various predictors were stepwise added to further models. First, the variable 'difficulties in limiting children's media consumption' was added. This model was significant ($F(4,142) = 7.412$, $p < .001$, *adjusted* $R^2 = 0.15$, $f^2 = .18$). Next, parents' perceptions of media preferences and addiction were added. This model was also significant ($F(5,141) = 18.94$, $p < .001$, *adjusted* $R^2 = 0.38$, $f^2 = .61$). The next model also included a predictor of how many hours a child could cope without media before experiencing problems, and this predictor was significant ($F(6,140) = 16.92$, $p < .001$, *adjusted* $R^2 = 0.4$, $f^2 = .67$). Finally, the average amount of daily media time that parents perceived as appropriate was added to the final model, which was also significant ($F(7,139) = 14.89$, $p < .001$, *adjusted* $R^2 = 0.4$, $f^2 = .67$). The models were then compared with each other. Adding the predictor of difficulty in restricting media use to the model containing the control variables resulted in a significant increase in explained variance ($F(1,142) = 32.53$, $p < .001$). Similarly, adding parents' perceptions of media preference and addiction, as well as how many hours children can easily cope without digital media, led to a significant increase in explained variance ($F(1,141) = 55.71$, $p < .001$ and $F(1,140) = 4.49$, $p = .036$). However, adding the maximum amount of time that parents considered appropriate to the final model had no significant effect on parents' concerns about media use ($F(1,139) = 1.99$, $p = .161$). Overall, hierarchical regression revealed that difficulties with restricting media use, perceptions of media preference and addiction, and the amount of time children can easily cope without media are significant predictors of parental concern about their child's media use. For the full results of any hierarchical regression analysis, see supporting information, S5 Appendix.

Discussion

This study examined whether the attitudes and concerns of parents differ between those with and without children with ASD. Essentially, this study revealed no difference in the amount of time spent using digital media between the two groups, which is consistent with the results of Pliska et al. [14]. With respect to parents' concerns about their child's media use, significant predictors were the difficulty of limiting media time, parents' perceptions that their child has a preference for and dependence on digital media, and the number of hours the child can cope without media. These predictors also correlate with parental concerns. The more parents worry about their child's media use, the more problematic it is for them to restrict it. Conversely, the less parents worry, the easier it is for them to restrict their child's media use. This result may therefore be related to findings by Kuo et al. [15], who showed that parents' concerns about media use are linked to mediation strategies, such as restricting use. Parents who are more concerned would therefore be more likely to restrict their children's media use, and thus more likely to encounter problems, than parents who are less concerned and therefore less likely to resort to restrictive control. Additionally, concerns increase with the perception that a child has a preference for and is dependent on digital media. On the other hand, the latter predictor correlates negatively with parents' concerns. This means that parents who say that their child can manage without digital media for longer without problems are less worried. This suggests that, according to parents, TD children can manage without media for longer than children with ASD without parents experiencing any problems in them. This result is consistent with the findings of a study by Coyne et al. [35], which showed that frequent use of media for emotional regulation was associated with more extreme emotions when the media was removed. Furthermore, the frequent use of media for emotional regulation was also associated with more problematic media use [35], which is also indicated by the findings of this study. The amount of time that parents say their child can cope without media correlates with the maximum amount of media time they consider appropriate. Therefore, it is not surprising that parents of children with ASD consider more time spent on digital media to be appropriate than parents of TD children. This may be related to the fact that parents of children with ASD find it more difficult to restrict their child's media consumption. There is also a significant correlation between the maximum appropriate time and the difficulty of restricting media use. As Pliska et al. [14] recently demonstrated, parents of children with ASD find it more challenging to limit their children's media consumption than parents of TD children. This is important, given that a study

by Konca [4] stated that limiting screen time is the most common strategy for regulating children's digital technology use. However, parents' concerns were not correlated with the maximum appropriate media time reported. This may also be because parents attribute more media skills to their child with ASD than to their TD child. Therefore, our finding that the maximum appropriate media time reported did not correlate with parental concerns and was not a predictor of them cannot support the findings of Laurie et al. [25], who reported a relationship between parental concerns about their children with ASD using technology and the amount of time spent using technology. In our study, however, we found that the more parents perceived their child to have a preference for digital media, the more they worried about media addiction and its negative effects on their child's health and behavior. Overall, parents with a child with ASD are more concerned about media addiction than parents with TD children. This finding lends weight to the evidence of Yuan et al. [7] that individuals with ASD are at a greater risk of becoming addicted to screens than those without ASD. In general, concerns about media addiction may be related to the fact that parents of children with ASD being more likely to perceive their child as having a preference for, and being addicted to, digital media than parents of TD children. However, concerns that children are losing touch with the real world through media consumption do not differ between the two groups. This may also be related to the previously mentioned differences in restricting media use and the number of hours a child can cope without media, as these factors correlate with concerns about media addiction. Furthermore, parents of children with ASD were found to be more concerned about the negative effects of media use on their children's health and behavior than parents of TD children, which supports the findings of MacMullin et al. [26]. However, concerns were not very high in either group.

No differences were observed between the groups regarding concerns about the development and intensification of ASD symptoms. Overall, concerns in this regard were stated as being very low, indicating that there is no concern that media use increases ASD symptoms. Notably, however, only concerns about the development and intensification of ASD symptoms were considered. However, it would also be worthwhile to ask whether media use improves ASD symptoms and, if so, whether they are absent or barely present during digital media use. For example, studies show that communication skills can be developed through digital media [33]. Additionally, parents of children with ASD state that they give their child digital media more often when they are unwell to help them self-regulate than do parents of TD children. This is consistent with findings by Gueron-Sela [34] and Coyne et al. [35] that parents use media to regulate their child's distress and manage their child's difficult emotions, respectively. However, the question arises as to whether parents are aware of this. It is possible that parents of children with ASD are more aware of it because screen media meet the sensory stimulation and solitary activity needs of children with ASD [27,28], and these parents are generally more engaged with their child's media use than parents of TD children. On one hand, this would explain, the group difference regarding giving the child media to self-regulate and on the other hand the small sample size in the TD group.

In summary, the two groups of parents have different concerns, with those of children with ASD worrying more than those of children with TD. This lends weight to the assumption by Laurie et al. [25] that the common concerns of parents may be exacerbated if their child has ASD. However, it should be noted that the concerns in both groups are not particularly pronounced. This suggests that parents of children either with or without ASD are not particularly concerned about their child's media use.

Limitations

Overall, the results should be interpreted with caution. This is first because of the small sample size and second because it was not possible to calculate exact *p*-values for the correlations due to ties (i.e., equal values). Additionally, it is possible that only individuals with a personal interest in the topic participated in the survey. This could have distorted the results and may also explain why the TD group was so small, despite many attempts to reach more families with a TD child. Perhaps digital media have simply become part of everyday life, to the extent that parents unconsciously integrate them into their TD children's daily routine without worrying about the issue of media use. In addition, no standardized questionnaire has been used, as, to the best of our knowledge, no standardized questionnaire is yet available for recording concerns

related to media use. However, the values for internal consistency (reliability) are satisfactory, except for the media skills scale. Furthermore, comorbid impairments in the ASD group were not considered in the results. It is possible that comorbid impairment influenced the results. However, most of the children in the ASD group also had ADHD. As a study by Hill et al. [38] showed that screen time was comparable in the ASD and ADHD groups and that earlier screen use was associated with more severe symptoms of ASD and ADHD, it can be assumed that the comorbid disorder did not greatly influence our results. Another limitation is the age range of 6–11 years, as this study revealed a positive correlation between age and the maximum amount of time that parents deemed appropriate for media use. Therefore, this sample may include children who have been exposed to media for a long time and have more experience with digital media, and children who have not. However, this does not necessarily affect the validity of the study's results, as age was not a significant factor in the hierarchical regression analysis and did not correlate with parental concerns. Furthermore, the study did not ask about parents' media consumption. Nevertheless, this information is important, as a study by Matthes et al. [23] showed that excessive smartphone use is associated with a loss of control over children's smartphone use. Parents' media consumption can therefore influence their children's media use and worries.

Implications

Future studies should also survey and consider parents' media consumption. The influence of parents' media consumption on their children's media use and their concerns in this regard should also be investigated. Additionally, the analyses should be repeated with a larger sample to create age- or media consumption-based clusters and examine parental concerns about media use. Overall, the study concluded that parental concerns about media use hardly differ between children with and without ASD and are generally very low. However, the study also revealed that parents with ASD find it more difficult to limit their child's media consumption, stating less often that the child can cope well without media and are increasingly aware that their child is dependent on digital media. For this reason, parents with a child with ASD should particularly be supported in limiting their child's media consumption if necessary. Despite this, it should also be emphasized that parents of children with ASD often rate their child's media skills better and use digital devices as a regulatory strategy. In this context, a study should investigate whether ASD symptoms improve with media use and whether this could explain the greater recommended maximum media time. For example, Griffith [24] showed that parents' more positive attitudes toward screen media were associated with higher media content consumption. Additionally, some studies suggest that the link between problematic screen use and ASD is likely because screen media fulfills the need for sensory stimulation and solitary activity [27,28] and helps individuals with ASD cope with social overstimulation [29]. A further study should examine the connections among high digital media consumption in children with ASD, the limited amount of time they can spend without digital media, parental difficulties in restricting their media use, and parents' perceptions that digital media is beneficial for their children, helping them regulate themselves and develop social skills. Overall, a study should examine whether and to what extent children behave differently when using digital media and whether ASD symptoms may not be present. This is important to investigate in the context of digitalization and the development of digital screenings because digital screenings can work only if ASD symptoms appear in a digital setting.

Conclusion

Overall, the study shows that parents of children with and without ASD are not particularly concerned about their children's media use. However, parents of children with ASD are slightly more concerned about media addiction and its negative effects on their children's health and behavior than parents of TD children. Predictors of parental concern about their child's media use include difficulty in limiting use, perception of preference and addiction, and how long children can cope without media. Furthermore, no differences were found in the concerns of parents with children with and without ASD regarding the development or intensification of ASD symptoms, although hardly any concerns were expressed in this regard. It should be noted that the results are based on a small sample, and that the survey may have been completed

primarily by parents who are already actively engaged with the issue of their children's media use. Additionally, parental media use, which can influence views and concerns about children's media use, was not considered. These aspects should be considered in a new study. Furthermore, the study only considered the development and intensification of ASD symptoms, and did not ask whether children's behavior and ASD symptoms improved as a result of media consumption. A new study should examine the positive and negative effects of media use on the behavior of children with and without ASD.

Supporting information

S1 Appendix. Questionnaire in German.
(PDF)

S2 Appendix. Translated questionnaire in English.
(PDF)

S3 Appendix. Subscales (translated in English).
(PDF)

S4 Appendix. R code: Data analysis.
(PDF)

S5 Appendix. Output hierarchical regression analysis.
(PDF)

S6 Appendix. Study data.
(XLSX)

S1 Table. Availability of digital media in the home and frequency of use (children with ASD: *n* = 117, TD children: *n* = 58).
(PDF)

S2 Table. Own property of digital media (children with ASD: *n* = 117, TD children: *n* = 58).
(PDF)

S3 Table. Devices available and usable in the children's room.
(PDF)

S4 Table. Average time spent on digital media per day.
(PDF)

S5 Table. The maximum amount of media time that parents consider appropriate per day (in min).
(PDF)

S6 Table. Age from which the child uses digital media almost daily.
(PDF)

S7 Table. Reasons for using digital media as named by parents across both groups (children with ASD: *n* = 117, TD children: *n* = 58).
(PDF)

S8 Table. Situations in which the child is given a digital device.
(PDF)

S9 Table. Parents' awareness of their children's use of digital media.
(PDF)

S10 Table. Rules for media use.
(PDF)

S11 Table. The amount of time that the child can cope without using media in their everyday life.
(PDF)

S12 Table. Necessity of media use for the child currently.
(PDF)

S13 Table. Code booklet for the Excel file containing the study data.
(PDF)

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Appendix C: Study III

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ORIGINAL ARTICLE

Media Equation of the Interaction of Children with Autism Spectrum Disorder: A Proof-of-Concept Approach Using an Equivalence Test in a Within-Subject Design

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Abstract
Digital technology promises to improve the process of identifying autism spectrum disorder (ASD). Specifically, an automated digital screening tool with avatar-based interaction may be appropriate for children to differentiate between typically developing children and those at risk for ASD. The first challenge is to verify media equation: children with ASD need to interact in a digital environment as they would in a face-to-face situation. Therefore, a warm-up/conversation situation was analyzed within five conditions representing a hierarchy of successive mediation: (a) face-to-face, (b) facetime, (c) avatar real-time, (d) video pre-recorded, (e) avatar pre-recorded. Data from 20 boys with ASD were analyzed in a within-subject design using an equivalence test. Approximate equivalence was found between all five conditions. The median across all conditions is 5 (verbal response related to the conversation). Most importantly, children with ASD behave similarly in the digital environment with an avatar as they do in a real-life situation with a human experimenter. We discussed implications for clinical practice.

Keywords Autism · Social interaction · Communication · Digital · Avatar · Media equation

Autism spectrum disorder (ASD) is a neurodevelopmental disorder characterized by long-term deficits in social interaction and communication, as well as repetitive and restricted behaviors, interests, or activities (Diagnostic and Statistical Manual of Mental Disorders– Fifth Edition; American Psychiatric Association, 2013). The global rate of ASD diagnosis has increased (Bougeard et al., 2021; Chiarotti & Venerosi, 2020), with approximately 1 in 100 children receiving this diagnosis worldwide (Zeidan et al., 2022). The average age at first diagnosis of ASD in Western countries is approximately 5 years (van't Hof et al., 2021), while children with intellectual disability are receiving an earlier diagnosis than those without (Höfer et al., 2019). In Germany, the average age at first diagnosis is as late as 6.5 years, when most children are already attending school and parents have expressed concerns from around the age of two onward (Höfer et al., 2019). One of the most reliable way to discriminate between individuals with ASD and typically developing (TD) individuals seems to administer tasks that aim to capture social communication and interaction (Mukherjee et al., 2024). For example, a systematic review and meta-analysis by Wood-Downie et al. (2021) revealed that individuals without ASD have better social interaction and communication abilities than individuals with ASD. Observing and evaluating interaction difficulties is a crucial part of diagnosing ASD and is therefore considered the gold standard (Lord et al., 2020). However, the process of evaluating social interaction and communication requires clinical expertise and is very time-consuming, which explains long waiting lists.

The longer waiting times for diagnosis in Germany than in other countries (Höfer et al., 2019), which is associated with uncertainty for the entire family (Wiggins et al., 2006) and delays the initiation of family support and child therapy (Tariq et al., 2018), clearly demonstrate the need for improved forms of care for suspected cases of ASD. This problem is addressed by the publicly funded project

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"Identification of Autism Spectrum Disorder using speech and facial expression recognition" (IDEAS). The project aims to develop a tablet-based digital screening tool that captures and automatically rates symptoms of ASD on the basis of speech, facial expression, and interaction and removes those candidates who are not suspected of having ASD from the waiting list. The implementation of new technologies could accelerate the diagnostic process and, as a result, facilitate earlier treatment for children with ASD.

In recent years, research into the clinical use of new technologies for ASD patients has increased, accelerated by the COVID-19 pandemic (Kumm et al., 2022). In particular, the process of ASD detection can be significantly improved via digital technologies (Dahiya et al., 2021; Desideri et al., 2021; Kohli et al., 2022). For example, Colombo et al. (2022) examined a web-based online screening tool for the detection of ASD and provided evidence for the integration of such screening services into primary care (Colombo et al., 2022). In addition, the results of the systematic review by Dahiya et al. (2021), which identified 16 studies on the use of new technologies to assess children with suspected ASD, strongly support live video assessment, video observation, and digital or telephone-based methods. Furthermore, Drimalla et al. (2019, 2020) reported that it is possible to predict the diagnosis of ASD with high accuracy on the basis of facial expressions, vocal characteristics, and gaze patterns via simulated dialog using video calls with a digital tool that they developed to automatically quantify biomarkers of social interaction deficits. Overall, the use of digital tools with objective data collection and analysis methods offers promising potential for the early detection of ASD.

Using a variety of sensors, such as those available in tablets (cameras with depth sensors, sound recordings, and touch-sensitive screens), ASD-related symptoms such as social-emotional and language skills can be recorded even in natural environments (Mukherjee et al., 2024). For example, Coffman et al. (2023) examine whether objective and quantitative measures of ASD-related behaviors collected via an app on a smartphone or tablet correlate with standardized caregiver and clinician ratings. The results confirm that the measured behaviors do in fact correlate with clinician ratings, indicating that the app can be useful in identifying ASD profiles (Coffman et al., 2023).

Automated digital screening using an avatar for interaction may be of particular interest to children with ASD (Georgescu et al., 2014) and may even be better for them. However, the results are contradictory. On the one hand, for example, in the study by Kellems et al. (2023), elementary-aged children with ASD (8–10 years) presented greater social engagement when they were interacting with an avatar than when they were interacting with a human. Here, four out of five children prefer to talk to an avatar rather than a human (Kellems et al., 2023). However, the explanation for this preference is not yet clear. One possible reason could be the more colorful presentation of a cartoonish avatar and its exaggerated facial expressions (Kellems et al., 2023). Another reason could be that interactions with an avatar are less socially demanding (Moore & Calvert, 2000). On the other hand, in contrast to Kellems et al. (2023), a study by Carter et al. (2014) suggested that humans are more effective than avatars in eliciting verbal and non-verbal communication in children aged 4–8 years ($n = 12$). In both studies, the avatar was not a human character, but a tropical fish in the study by Kellems et al. (2023) and a turtle in the study by Carter et al. (2014), as in the movie "Finding Nemo". In both cases, the avatar was controlled live by the experimenters via a computer. In contrast to the study by Carter et al. (2014), Kellems et al. (2023) had the experimenter introduce the interaction with the avatar by having a short conversation with the avatar to demonstrate how to communicate properly with it. This may also have contributed to a preference for interaction with the avatar. In conclusion, further research into mediated communication is needed, as is validation of the diagnostic comparability of real and simulated interactions for the specific needs of individuals with ASD.

To achieve the goal of developing automated digital screening for ASD, the first step and aim of this research was therefore to test the media equation, i.e., whether children with ASD interact in a digital environment as they would in a face-to-face situation. The media equation implies that people perceive technology-mediated experiences in the same way as nonmediated experiences do (Lee, 2008; Reeves & Nass, 1996). This is because interacting with media is essentially social and natural, similar to interacting in real life (Reeves & Nass, 1996). This can be supported by the *rich-get-richer hypothesis* (Valkenburg & Peter, 2007), which suggests that adolescents show continuity in social interaction across settings, including computer-mediated communication (CMC). Correspondingly, individuals who have communication difficulties in real life might also have difficulties with CMC (Paulus et al., 2020). These findings suggest that individuals with ASD could also have difficulties with social communication in the digital environment. On the other hand, individuals with ASD report that interaction via CMC does not replace face-to-face interaction because of reduced social information (Cummings et al., 2002; Ritzman & Subramanian, 2024). Therefore, it can also be assumed that individuals with ASD, for whom face-to-face interaction is challenging, may be attracted to and can benefit from CMC (MacMullin et al., 2016; Shane & Albert, 2008; van der Aa et al., 2016). Bagatell (2010) suggested that it can give individuals the opportunity to interact with others in terms of the safety and security of a familiar

place. This finding is supported by the study by Cardon and Azuma (2012), in which children with ASD preferred video presentations over live presentations. The participants' visual attention was greater during the video presentation than during the live presentation (Cardon & Azuma, 2012). Thus, the results suggest that visual attention in children with ASD can be influenced by the type of presentation (Cardon & Azuma, 2012).

In summary, the theory of media equation suggests that people behave in the same way in a digital environment as they do in a real environment, but the state of research also shows that there may be a preference for digital presentation, and it is also unclear how avatars affect the interaction of children with ASD. However, media equation is often simply assumed in the development of digital screening tools for children with suspected ASD. To the best of our knowledge, no study has investigated this underlying assumption prior to the development of a digital screening tool. However, for digital screening to be successful, the symptoms of ASD must be elicited and presented to discriminate between children with and without ASD (important here: sensitivity and specificity). This means that children must behave in the same way in a digital situation as they would in a real situation. The purpose of this paper is therefore to address this research gap via a proof-of-concept approach by addressing the following question:

1) Do children with ASD interact in a digital environment in the same way that they would interact in a face-to-face situation?

Materials and Methods

The materials and methods used in the proof-of-concept study, including details on the research design, are presented in the following sections. Prior to the study, a positive ethics vote was obtained from the ethics committee, Department of Rehabilitation Sciences, TU Dortmund University (GEKTUDO_2022_45).

Participants

Families with children diagnosed with ASD were recruited in 2023 and 2024 from autism therapy facilities in a German metropolitan area as a part of a larger research project (IDEAS) on the medial elicitation of ASD-associated symptoms. Written information about the study was mailed or given to the families by the staff of the autism therapy facilities, after which the families contacted the study manager if they were interested, had their questions answered, and provided written consent. The children were also informed verbally and asked for their consent at the testing appointment. Demographic information about the families and children (e.g., age, highest level of parental education, diagnoses, IQ, information about language skills) was collected through a parent questionnaire at the testing appointment.

The inclusion criteria were preceded by special considerations regarding gender aspects. Research highlights that more is known about boys with ASD, who are diagnosed more often than girls, with a male-to-female ratio of approximately 3:1 (Elsabbagh et al., 2012; Jiménez-Muñoz et al., 2022; Loomes et al., 2017; Zeidan et al., 2022). Girls may be misdiagnosed or diagnosed later because their ASD symptoms present differently (Hodges et al., 2020; Hull et al., 2020); for example, they tend to have better social interaction and communication skills (Wood-Downie et al., 2021). However, to approximate the highly heterogeneous population in terms of symptoms, the current phase of the study included only boys aged 6–11 years (elementary school age), who are verbally fluent and have no cognitive impairment.

For an initial proof-of-concept within-subject design, 20 monolingual German-speaking boys diagnosed with ASD were recruited. Only one participant was bilingual. Most of the participants ($n=16$) achieved a sufficient score ($T \geq 40$) on the Test of Grammar Comprehension (German adaptation of the Test for Reception of Grammar; Fox-Boyer, 2023), which was lower for four children (reasons for cancellation: lack of motivation and concentration, bilingualism). The standardized test assesses comprehension of a variety of syntactic structures of increasing complexity. In total, the children achieved a mean T-score of 52.68 ($SD=17.99$) on the German adaptation of the Test for Reception of Grammar. Therefore, problems in answering the questions should not be due to a lack of language comprehension.

The mean age of the boys was 112.75 months ($SD=20.82$), i.e., 9.4 years. Despite the diagnosis of ASD, parents did not report any additional physical diagnoses or cognitive impairments for these children. However, five children had a psychiatric diagnosis of impulse control disorder, two had attention deficit hyperactivity disorder, two boys had both and one child had epilepsy. All participants had adequate vision and hearing (vision corrected with glasses in $n=5$). All diagnostic information was provided by the parents and was based on medical examinations and parent questionnaires. Most families ($n=16$) reported a high school diploma as the highest level of education. Four families reported that they had a lower level of education.

Research Design and Testing Materials

To investigate whether children with ASD interact in digital formats in the same way as they would face-to-face, a

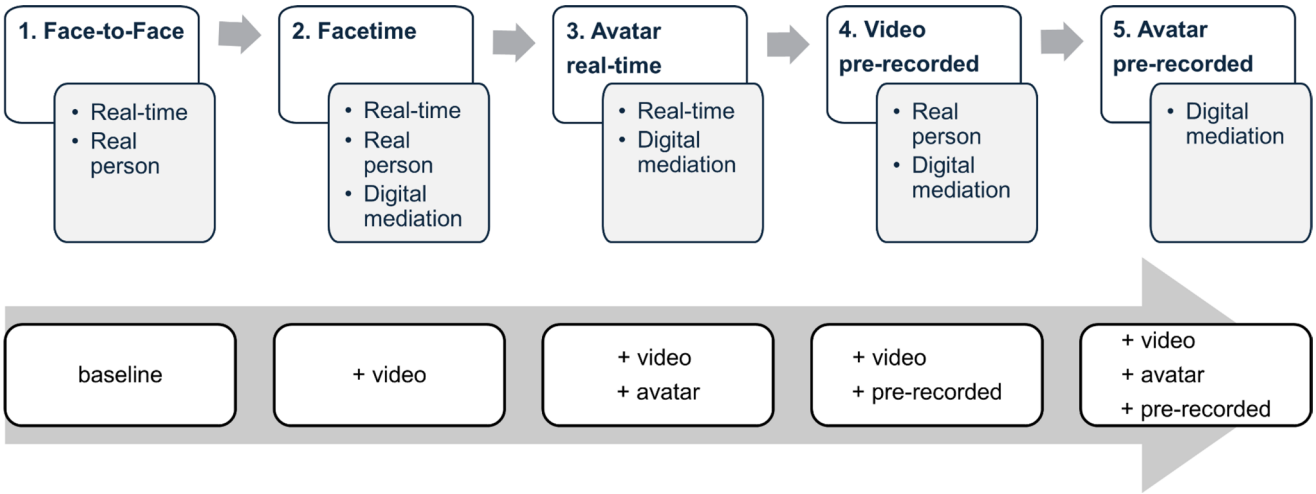

Fig. 1 The conditions in the current investigation were counterbalanced in characteristics concerning the authenticity of communication and the child's interlocutor (experimenter). The conditions are presented in the upper boxes, and the characteristics are visualized on the x-axis (Figure based on Pliska et al., 2023)

Table 1 Example of test material (Personal Translation)

Condition	Question 1	Question 2	Question 3
3: Avatar real-time	What is actually your favorite food?	What is your favorite drink?	What is your favorite sweet?
5: Avatar pre-recorded	Which animals do you actually like?	What is your favorite animal?	What other animals do you like?

within-subject design was implemented with five conditions representing a hierarchy of successive digital mediations (see Fig. 1).

The face-to-face condition was considered the baseline condition because it closely resembles everyday conversations as well as typical face-to-face assessments in gold standard ASD diagnostics (described in Kamp-Becker et al., 2021). From there, the conditions varied in time (real-time vs. pre-recorded) and in the authenticity of the interlocutor (real person 'live' vs. pre-recorded, digital avatar 'live' vs. pre-recorded). Overall, the conditions can be grouped into different clusters that face each other. One possibility is a real person (conditions 1, 2, and 4) vs. an avatar (conditions 3 and 5). Another option is real-time (conditions 1, 2, and 3) vs. pre-recorded (conditions 4 and 5). The digital avatar, created via Apple's Memoji software (Apple Inc., 2023), visually mimicked the real-person experimenter conducting the test.

Each child participated in two sessions and completed all five conditions. To control for systematic effects, the conditions were fully counterbalanced. For example, one child went through the conditions in order 1, 2, 3, 4, and 5, the next child in order 2, 3, 4, 5, and 1, then a child in order 5, 4, 3, 2, and 1, and so on, so that no child had the same order. The conditions and their characteristics are shown in Fig. 1, with the conditions shown in upper boxes and the characteristics visualized on the x-axis. In each condition, tasks were set to elicit behavior related to interaction, among other things. These tasks are designed to potentially elicit symptoms of ASD, such as deficits in social interaction and communication (American Psychiatric Association, 2013).

The task to induce interactional behavior in an interview sequence (warm-up/conversational situation task) was always performed at the beginning of each condition (methodologically inspired by Drimalla et al., 2019, 2020). To ensure comparable content under each condition while avoiding repetitive behavior, the content used in each condition was parallelized. The interview sequence followed a similar question sequence (e.g., open-ended question, decision question, open-ended question), but different age-appropriate topics of conversation were chosen (e.g., seasons, animals, etc.; see an example in Table 1). This approach allowed for variation in conditions while maintaining consistency in content. In addition, the experimenter performs the task via a script so that the experimenter always interacts in a neutral and consistent manner. This procedure was practiced by the experimenter in a pre-test in advance.

Testing Procedure

The tests were conducted via extensive and sophisticated technical equipment. To facilitate communication in the digitally mediated conditions, several iPads (including an iPad Pro 11", 3rd gen.; running iPad OS 16.3) and Apple's FaceTime technology (iPad OS version 16.3; Apple Inc., 2023) were used. The speech component of the test was recorded

via a TASCAM DR-40X recorder and a Sennheiser MEB table microphone for speech analysis.

Figure 2 provides a visual representation of the test setup. The child is seated with an unobstructed view of the external screen displaying the digitally mediated conditions and the experimenter in the face-to-face condition. An external camera is positioned diagonally in front of the child. This camera records the entire test. A technical assistant is positioned behind the child and monitors and controls the stimuli throughout the test.

Each child is tested in the same room with a low level of stimuli. Children 1 to 16 were tested in a room at the autism therapy center where the child received therapy sessions. Children 17 to 20 were tested in the testing room at the university.

Data Analysis

To compare the interaction in the different media formats for each individual child with ASD, the warm-up/conversational situation task was analyzed. For this purpose, the videos of the tests were coded by two independent raters on an ordinal scale from 1 (no response), 2 (non-verbal or other reactions not related to the conversation), 3 (verbal response not related to the conversation), 4 (non-verbal or other reactions related to the conversation) to 5 (verbal response related to the conversation). Zero is a residual category that includes "no idea", "don't know", or responses given after further prompting. First, both raters were given videos of the test and evaluated them, clarifying any uncertainties with the test administrator. For example, if the child simply waves at the screen in response to the question "Which animals do you actually like?", this would be coded as a 2. If the child imitates a cat, it would be a 4. If the child says, "We went to the zoo yesterday," it would be a 3. Only if the child names a specific animal would it be assigned a score of 5.

Interrater reliability was calculated for 15% of the coding via Krippendorff's alpha with the "stringr" package (Wickham and Posit Software, 2023) in R (R Core Team, 2023, version 4.3.1). For all three variables of the warm-up/conversational situation task, Krippendorff's alpha is 1, indicating perfect agreement (see Zapf et al., 2016) and highlighting the objectivity of the rating categories. Descriptive and statistical analyses to test whether there was no difference– i.e. equivalence– in the interaction between conditions were also performed via R (R Core Team, 2023, version 4.3.1). One statistical way to test for equivalence is the two one-sided test (TOST; Lakens et al., 2018). We adjusted the TOST to be based on the Wilcoxon signed rank test– due to the small sample size and non-normal distribution– with mu = 0.5 (equivalence would be rejected with a 0.5 difference in encoding) and Bonferroni correction. The Bonferroni correction divides the original significance level ($\alpha = 0.05$) by the number of tests performed to reduce the likelihood of false positives. The Wilcoxon signed rank test was used over other non-parametric tests because it is best used with ordinal data with non-normal distribution (Caldwell, 2025). Since equivalence is tested and the effect size is always related to a difference, it can be assumed that

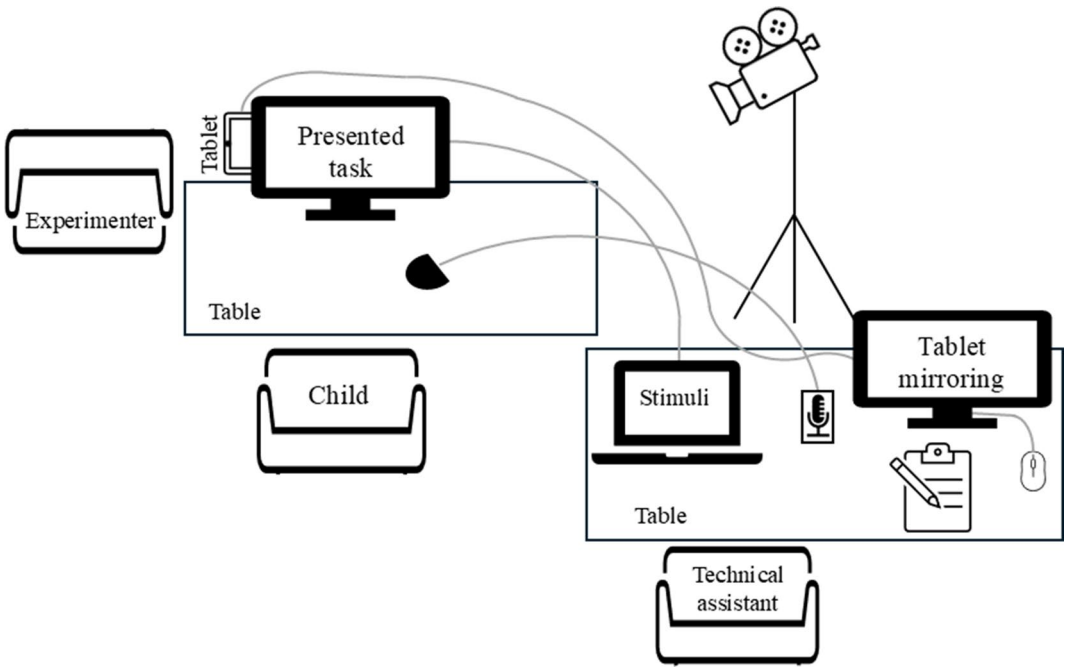

Fig. 2 Test Setting in the Current Investigation

the smaller the effect, the more it indicates equivalence. The dependent variable was always the score of the question (ordinal score from one to five; see above), and the independent variable was the condition (condition 1 vs. 2 vs. 3 vs. 4 vs. 5 or real person vs. avatar or real-time vs. prerecorded).

Results

Figure 3 show the codes for each question and condition per child. At the individual level, children 2, 9, 18 and 20 interacted differently between conditions. This was the case for all three questions. For children 1, 5, 12 and 13, this was only the case for 2 out of 3 questions. Children 3, 4, 6, 11, 16, 17 and 19 interacted identically in each condition and for each question, namely, verbally in relation to the conversation (score 5). The other children showed a deviation in their interaction in only one question for one condition; otherwise, they interacted in the same way across all conditions.

Table 2 displays the proportions (in %) of the type of interaction within a condition between the questions. In Question 1, 100% of the children gave a verbal response that was related to the conversation within condition 1, and 95% of the children in conditions 2 and 4, the real person conditions. In conditions 3 and 5 (avatar conditions), this was the case for fewer children (condition 3: 80%; condition 5: 85%). In question 2, 95% of the participants gave a verbal response that was related to the conversation within condition 3 and 90% in conditions 1 and 2 (real-time conditions), and 5% provided a verbal response that was not related to the conversation (conditions 1 and 3). In conditions 4 and 5 (pre-recorded conditions), a verbal response to the conversational response was given by fewer children: 80% in condition 5 and 75% in condition 4. In both conditions, there are more than two different responses or reactions. For question 3, in conditions 1 and 3, 95% of the children responded verbally related to the conversation. In condition 5, it was 90%, and in conditions 2 and 4, it was 80%. In condition 2 and 4, there are more than two different responses or reactions. An overview is also shown in Fig. 4.

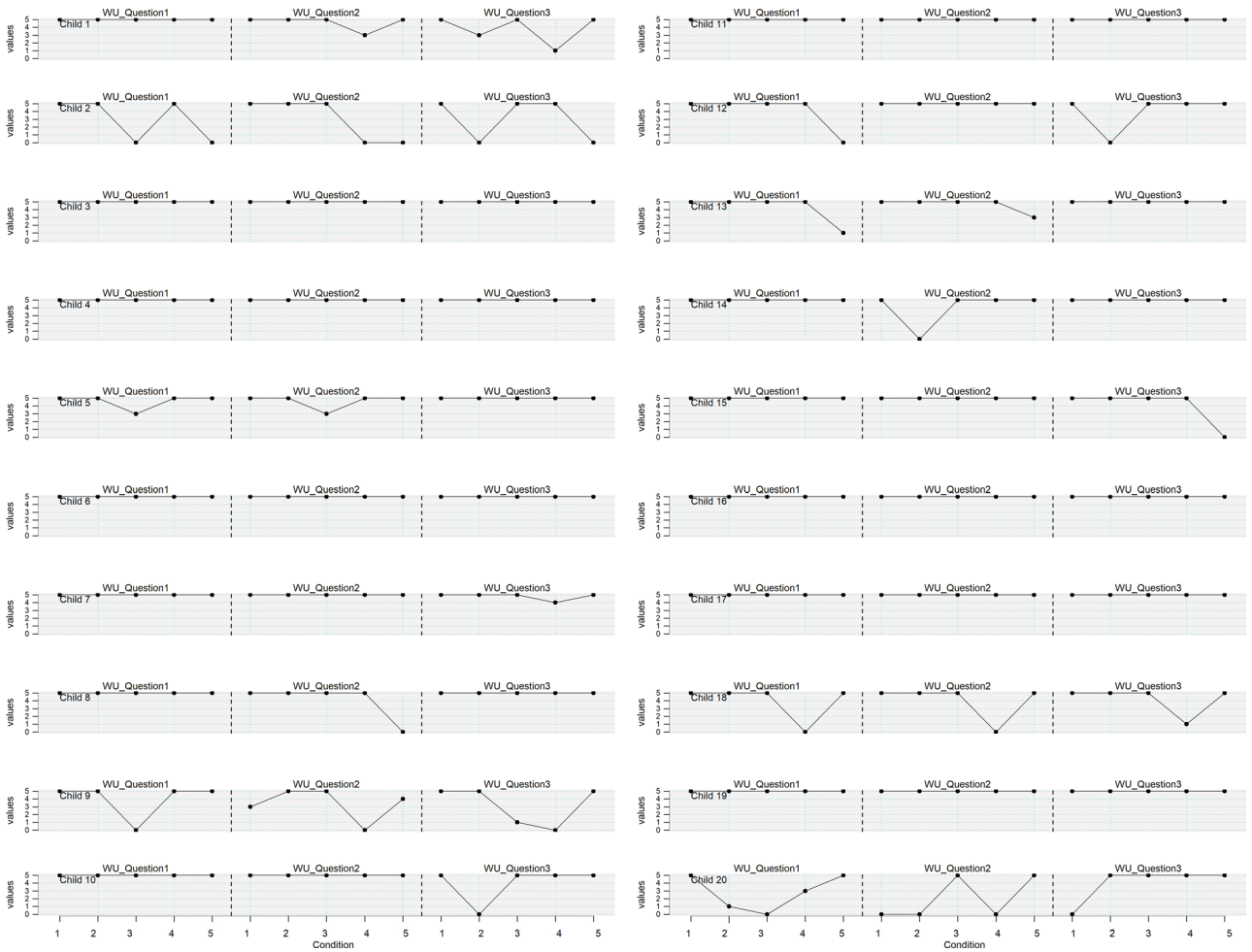

Fig. 3 Single Case Presentation of Children 1 to 20

Table 2 Percentage distribution of the interaction

Task–Question	Value/Code	Condition				
		1. Face-to-Face	2. Facetime	3. Avatar real-time	4. Video pre-recorded	5. Avatar pre-recorded
Warm-up– Question 1	0	/	/	15%	5%	10%
	1	/	5%	/	/	5%
	2	/	/	/	/	/
	3	/	/	5%	/	/
	4	/	/	/	/	/
	5	100%	95%	80%	95%	85%
Warm-up– Question 2	0	5%	10%	/	20%	10%
	1	/	/	/	/	/
	2	/	/	/	/	/
	3	5%	/	5%	5%	5%
	4	/	/	/	/	5%
	5	90%	90%	95%	75%	80%
Warm-up – Question 3	0	5%	15%	/	5%	10%
	1	/	/	5%	10%	/
	2	/	/	/	/	/
	3	/	5%	/	/	/
	4	/	/	/	5%	/
	5	95%	80%	95%	80%	90%

Note. 0 = residual category, 1 = no response, 2 = Other reaction not related to the conversation, 3 = verbal response not related to the conversation, 4 = mimic or other reaction related to the conversation, 5 = verbal response related to the conversation; $n = 20$

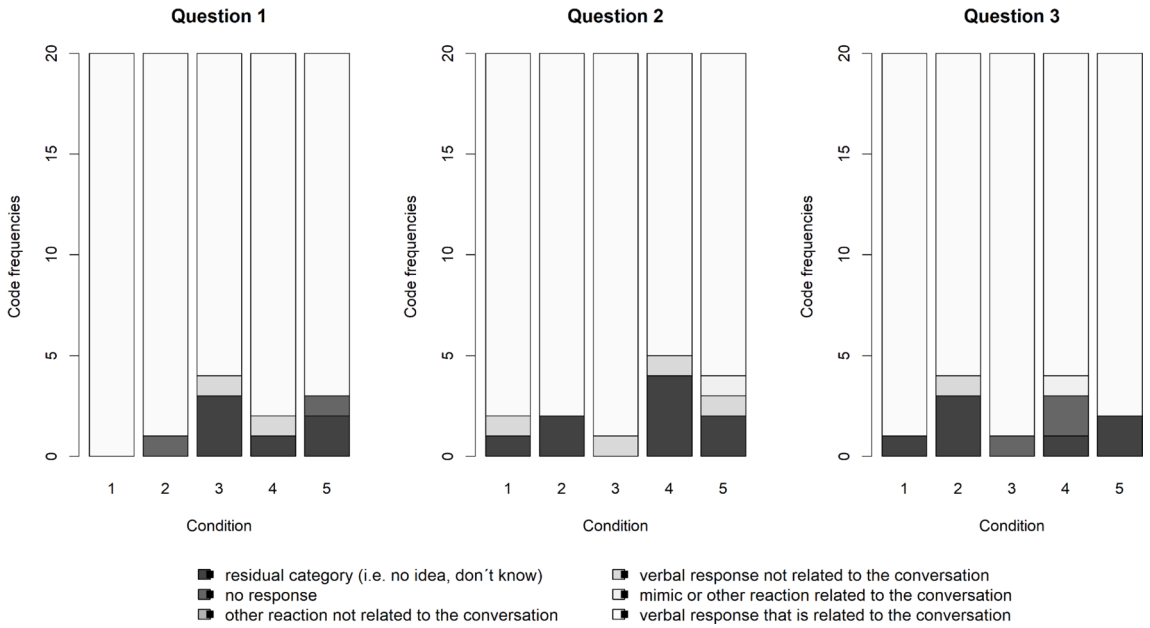

Fig. 4 Answers by Condition and Question for Individuals with ASD (n = 20). Conditions: 1 = Face-to-Face, 2 = Facetime, 3 = Avatar real-time, 4 = Video pre-recorded, 5 = Avatar pre-recorded

Results of Equivalence Testing for Each Item

Overall, the median across all children and all conditions is 5 (see Table 3). Conversely, the mean values of the raw conversation scores show some variation between conditions.

In question 1, only condition 1 has a median of 5 and a mean of 5.00 ($SD = 0$), so each boy gives a verbal response related to the conversation. Conditions 2 and 4 also have a median of 5 but a mean of 4.80 ($SD = 0.89$) in condition 2 and a mean of 4.65 ($SD = 1.18$) in condition 4. The small differences in the means are due to the fact that one child, in each condition, did not give a verbal conversational response. However, equivalence can be assumed due to the percentage frequency of 100% verbal conversational response in

Table 3 Descriptive Data of analysis for individuals with ASD (n=20)

Condition	Task											
	Warm-up– Question 1				Warm-up– Question 2				Warm-up– Question 3			
	min	max	Md	M(SD)	min	max	Md	M(SD)	min	max	Md	M(SD)
1. Face-to-Face	5	5	5	5.00 (0.00)	0	5	5	4.65 (1.18)	0	5	5	4.75 (1.12)
2. Facetime	1	5	5	4.80 (0.89)	0	5	5	4.50 (1.54)	0	5	5	4.15 (1.84)
3. Avatar real-time	0	5	5	4.15 (1.84)	3	5	5	4.90 (0.45)	1	5	5	4.80 (0.89)
4. Video pre-recorded	0	5	5	4.65 (1.18)	0	5	5	3.90 (2.05)	0	5	5	4.30 (1.59)
5. Avatar pre-recorded	0	5	5	4.30 (1.72)	0	5	5	4.35 (1.57)	0	5	5	4.50 (1.54)
Pre-recorded	2.5	5	5	4.48 (0.98)	0	5	5	4.13 (1.44)	2.5	5	5	4.00 (1.02)
vs.												
Real-time	2	5	5	4.65 (0.81)	1.67	5	5	4.68 (0.82)	3.3	5	5	4.57 (0.71)
Avatar	0	5	5	4.23 (1.39)	2.5	5	5	4.63 (0.79)	2.5	5	5	4.65 (0.86)
vs.												
Real Person	3	5	5	4.82 (0.57)	0	5	5	4.35 (1.27)	3	5	5	4.40 (0.86)

condition 1 and 95% in conditions 2 and 4 (see Table 2). These are real person conditions. In the conditions involving the avatar, the means are smaller (condition 3: $M=4.15$, $SD=1.84$; condition 5: $M=4.30$, $SD=1.72$). In conditions 3 and 5 of question 1, only 80% in condition 3 and 85% in condition 5 gave a verbal conversational response. Two children in condition 5 and three children in condition 3 did not answer verbally in a conversational manner but answered "no idea", "don't know", or only when prompted. In addition, one child in condition 3 gave a verbal, nonconversational response, and one child in condition 5 gave no response. Overall, the mean value in the real person conditions is 4.82 ($SD=0.57$) and 4.23 ($SD=1.39$) in the avatar conditions. When considering the pre-recorded conditions (conditions 4 and 5) are compared with the real-time conditions (conditions 1, 2 and 3), the mean for the pre-recorded conditions is 4.48 ($SD=0.98$), and for the real-time conditions is 4.65 ($SD=0.81$). Question 1 shows significant equivalence only between conditions 1 (Face-to-Face) and 2 (Facetime) and between conditions 2 (Facetime) and 4 (Video pre-recorded; see Table 4). These are real person conditions. For question 1, the mean difference between an avatar and a real person is greater (0.59; $M=4.23$ and $M=4.82$) than for questions 2 (0.28; $M=4.63$ and $M=4.35$) and 3 (0.25; $M=4.65$ and $M=4.40$).

In question 2, only condition 3 had a median of 5 and a mean of 4.90 ($SD=0.45$) because 95% of the children gave a verbal conversational response. The mean value of condition 1 is 4.65 ($SD=1.18$), and of condition 2 is 4.50 ($SD=1.54$), where 90% of the children gave a verbal conversational response. One child in each of conditions 1 and 3 gave a verbal response that was not conversational, and one child in condition 1 and two children in condition 2 answered 'no idea', 'don't know' or only when prompted. Conditions 1, 2 and 3 are real-time conditions. The averages of the pre-recorded conditions are different (condition 4: $M=3.90$, $SD=2.05$; condition 5: $M=4.35$, $SD=1.57$), where the interaction was more variable in conditions 4 and 5 (see Tables 2 and 3). Overall, the mean for the pre-recorded conditions is 4.13 ($SD=1.44$), and for the real-time conditions, it is 4.68 ($SD=0.82$). For question 2, the mean value was 4.63 ($SD=0.79$) in the avatar conditions and 4.35 ($SD=1.27$) in the real person conditions. Question 2 also shows a significant equivalence between conditions 1 (Face-to-Face) and 2 (Facetime), i.e., the real person and real-time conditions (see Table 4). The comparison between all three real-time conditions (1, 2 and 3) was just below significance in TOST. Therefore, the mean difference between real-time and pre-recorded conditions is greater for question 2 (0.55; $M=4.68$ and $M=4.13$) than for question 1 (0.17; $M=4.65$ and $M=4.48$) but very similar to question 3 (0.57; $M=4.57$ and $M=4.00$).

In question 3, the median for each condition is 5. The mean of condition 1 is 4.75 ($SD=1.12$), and that of condition 3 is 4.80 ($SD=0.89$). In both conditions, 95% of the children gave a verbal response related to the conversation. Condition 2 has a mean value of 4.15 ($SD=1.84$), condition 4 has a mean of 4.30 ($SD=1.59$), and condition 5 has a mean of 4.50 ($SD=1.54$). Here, 90% of the children in condition 5 gave a verbal response related to the conversation, and 80% of the children in conditions 2 and 4 gave a verbal response. Therefore, it can be assumed that conditions 1, 3, and 5 are almost equivalent. However, question 3 only shows a significant equivalence between conditions 1 and 3, i.e., between a real person and an avatar (see Table 4). The comparison with condition 5 was just below significance. Question 3 has a mean of 4.00 ($SD=1.02$) in the pre-recorded conditions and 4.57 ($SD=0.71$) in the realtime conditions and 4.65 ($SD=0.86$) in the avatar conditions and 4.40 ($SD=0.86$) in the real person conditions.

In summary, Table 4 displays the results of the equivalence test. Question 1 shows significant equivalence only between conditions 1 (Face-to-Face) and 2 (Facetime) and between conditions 2 (Facetime) and 4 (Video

Table 4 Equivalence Test

Question		Comparison (G1 vs. G2)	*N*	Median		TOST			Effect Size
				G1	G2	Lower *p*.value	Upper *p*.value	Test Decision	
1	WU_Question1	Avatar pre-recorded vs. Avatar real-time	20	5	5	0.0315	0.1951	TOST H0 cannot be rejected	-0.086
2	WU_Question1	Avatar pre-recorded vs. Face-to-Face	20	5	5	0.2776	0.0001	TOST H0 cannot be rejected	0.271
3	WU_Question1	Avatar pre-recorded vs. Facetime	20	5	5	0.2448	0.0025	TOST H0 cannot be rejected	0.186
4	WU_Question1	Avatar pre-recorded vs. Video pre-recorded	20	5	5	0.2358	0.0263	TOST H0 cannot be rejected	0.095
5	WU_Question1	Avatar real-time vs. Face-to-Face	20	5	5	1.0000	0.0002	TOST H0 cannot be rejected	0.352
6	WU_Question1	Avatar real-time vs. Facetime	20	5	5	0.6033	0.0002	TOST H0 cannot be rejected	0.352
7	WU_Question1	Avatar real-time vs. Video pre-recorded	20	5	5	0.8756	0.0034	TOST H0 cannot be rejected	0.248
8	WU_Question1	Face-to-Face vs. Facetime	20	5	5	0.0001	0.0021	significant equivalence	-0.095
9	WU_Question1	Face-to-Face vs. Video pre-recorded	20	5	5	0.0001	0.0366	TOST H0 cannot be rejected	-0.186
10	WU_Question1	Facetime vs. Video pre-recorded	20	5	5	0.0023	0.0027	significant equivalence	-0.005
11	WU_Question2	Avatar pre-recorded vs. Avatar real-time	20	5	5	0.5585	0.0027	TOST H0 cannot be rejected	0.262
12	WU_Question2	Avatar pre-recorded vs. Face-to-Face	20	5	5	0.2250	0.0096	TOST H0 cannot be rejected	0.095
13	WU_Question2	Avatar pre-recorded vs. Facetime	20	5	5	0.3685	0.0342	TOST H0 cannot be rejected	0.148
14	WU_Question2	Avatar pre-recorded vs. Video pre-recorded	20	5	5	0.0254	0.8359	TOST H0 cannot be rejected	-0.171
15	WU_Question2	Avatar real-time vs. Face-to-Face	20	5	5	0.0024	0.0368	TOST H0 cannot be rejected	-0.095
16	WU_Question2	Avatar real-time vs. Facetime	20	5	5	0.0024	0.0414	TOST H0 cannot be rejected	-0.100
17	WU_Question2	Avatar real-time vs. Video pre-recorded	20	5	5	0.0025	1.0000	TOST H0 cannot be rejected	-0.352
18	WU_Question2	Face-to-Face vs. Facetime	20	5	5	0.0023	0.0027	significant equivalence	-0.005
19	WU_Question2	Face-to-Face vs. Video pre-recorded	20	5	5	0.0002	1.0000	TOST H0 cannot be rejected	-0.352
20	WU_Question2	Facetime vs. Video pre-recorded	20	5	5	0.0029	0.8750	TOST H0 cannot be rejected	-0.252
21	WU_Question3	Avatar pre-recorded vs. Avatar real-time	20	5	5	0.0366	0.0024	TOST H0 cannot be rejected	0.100
22	WU_Question3	Avatar pre-recorded vs. Face-to-Face	20	5	5	0.0325	0.0024	TOST H0 cannot be rejected	0.090
23	WU_Question3	Avatar pre-recorded vs. Facetime	20	5	5	0.0029	0.2231	TOST H0 cannot be rejected	-0.171
24	WU_Question3	Avatar pre-recorded vs. Video pre-recorded	20	5	5	0.0340	0.3685	TOST H0 cannot be rejected	-0.138
25	WU_Question3	Avatar real-time vs. Face-to-Face	20	5	5	0.0023	0.0025	significant equivalence	-0.005
26	WU_Question3	Avatar real-time vs. Facetime	20	5	5	0.0029	0.9712	TOST H0 cannot be rejected	-0.267
27	WU_Question3	Avatar real-time vs. Video pre-recorded	20	5	5	0.0002	0.2843	TOST H0 cannot be rejected	-0.352
28	WU_Question3	Face-to-Face vs. Facetime	20	5	5	0.0029	0.8750	TOST H0 cannot be rejected	-0.252
29	WU_Question3	Face-to-Face vs. Video pre-recorded	20	5	5	0.0034	0.4744	TOST H0 cannot be rejected	-0.243
30	WU_Question3	Facetime vs. Video pre-recorded	20	5	5	0.2233	0.2825	TOST H0 cannot be rejected	-0.038

Table 5 Descriptive Analysis of the conditions in the Warm-Up task for individuals with ASD (n = 20)

Condition	Warm-up task			
	min	max	Md	M(SD)
1. Face-to-Face	1.67	5	5	4.80 (0.75)
2. Facetime	2	5	5	4.48 (0.90)
3. Avatar real-time	2	5	5	4.62 (0.84)
4. Video pre-recorded	0.33	5	5	4.28 (1.36)
5. Avatar pre-recorded	0	5	5	4.38 (1.25)
Pre-recorded	1.67	5	5	4.33 (0.93)
Real-time	3.78	5	5	4.63 (0.66)
Avatar	1.67	5	5	4.50 (0.83)
Real Person	2.11	5	5	4.52 (0.76)

pre-recorded). These are real person conditions. Question 2 also shows a significant equivalence between conditions 1 (Face-to-Face) and 2 (Facetime), i.e., the real person and real-time conditions. Question 3 only shows a significant equivalence between conditions 1 (Face-to-Face) and 3 (Avatar real-time). For the remaining comparisons between conditions, the null hypothesis of TOST (H0: difference in the interaction between conditions) could not be rejected. However, some of the comparisons just missed the significance threshold: for question 1 between conditions 1 and 4 (real person), for question 2 between conditions 1 and 3 and between conditions 2 and 3 (real-time), and for question 3 between conditions 3 and 5 and between conditions 1 and 5 (real person– avatar).

Overall, the largest, however small effect to be found is for question 1 between conditions 3 and 1 and conditions 3 and 2 (effect size of approximately 0.3). In particular, the effects for the demonstrated equivalences are as good as 0, which also supports equivalence. Overall, the effects close to 0 indicate equivalence between the conditions in the questions.

Overall Results of the Task

Table 5 shows the descriptive analysis of the conditions in the warm-up task where the three questions were averaged. All conditions have a median of 5. The means between conditions and after clustering differ only slightly from each other. It only varies between a mean of 4.28 and 4.80. The mean value of condition 1 is 4.80 ($SD = 0.75$), of condition 2 is 4.48 ($SD = 0.90$), of condition 3 is 4.62 ($SD = 0.84$), of condition 4 is 4.28 ($SD = 1.36$), and of condition 5 is 4.38 ($SD = 1.25$). Comparing the pre-recorded and real-time conditions, the pre-recorded conditions have a mean of 4.33 ($SD = 0.93$), and the real-time conditions have a mean of 4.63 ($SD = 0.66$). The mean difference between the pre-recorded and real-time conditions is 0.30 ($M = 4.33$ and $M = 4.63$). The mean of the avatar vs. real person comparison was 4.50 ($SD = 0.83$) for the avatar conditions and 4.52 ($SD = 0.76$) for the real person conditions. The mean difference between the avatar and real person conditions is even smaller (0.02; $M = 4.50$ and $M = 4.52$).

Discussion

The present study investigated how children with ASD interact with a differently mediated interlocutor. The results are interpreted in relation to the research question of whether children with ASD interact in the same way with differently mediated interlocutors.

Question item 1 shows no differences when interacting with a real person but slight differences when interacting with an avatar. This is also confirmed by the analysis result, which shows a significant equivalence between conditions 1, 2, and 4. Thus, our results support the findings of the study by Carter et al. (2014) that humans are more effective at eliciting communication than avatars. In addition, our results contradict those of the study by Kellems et al. (2023), in which the majority of the children indicated a preference for communicating with an avatar over a human. This can be partially supported by the results of question item 2. The findings revealed significant equivalence between conditions 1 and 2, which are real-time conditions with a real person. However, the third question item shows no difference between a real person in real-time and an avatar in real-time in the analysis results. Overall, equivalence was found in real-time conditions. Therefore, our findings do not support those of Cardon and Azuma (2012), who reported that children with ASD exhibited a preference for videos over live presentations. The results of the present study indicate that there were no significant differences in the interactions with real-time communication partners. However, differences were observed in the interactions with pre-recorded communication partners. To the best of our knowledge, the interaction between a real-time communication partner and a pre-recorded communication partner has not yet been investigated. For example, the studies by Carter et al. (2014) and Kellems et al. (2023) also only examined the interaction in real-time conditions, as in both studies, the experimenter controlled the avatar live via a computer. Furthermore, the results of both studies must be viewed with caution, as the sample size in both studies was very small (Carter et al., 2014: $n = 12$; Kellems et al., 2023: $n = 5$). Notably, in both studies, the avatar was not a human animated avatar but rather an animal, as in the movie "Finding Nemo" (Carter et al., 2014; Kellems et al., 2023). In the study by Kellems et al. (2023), a pilot study was conducted to determine whether to use an animated fish or a human animated character. In their pilot study, animated fish were chosen because animated human characters are

often distracting and uncomfortable for children (Kellems et al., 2023). It is therefore surprising that the children in our study interacted with the human animation avatar as well as with the real person. This may also explain why we see such large differences in interaction between conditions for children 2, 9, 18, and 20 (see Fig. 3). These differences could be avoided by having the experimenter speak to the human avatar on the screen in front of the child at the beginning, as was done in the study by Kellems et al. (2023). Other reasons for these differences may be that all four children received additional prompts from the experimenter's technical assistant; therefore, the responses had to be coded as 0 because the additional prompts may have biased the results. Notably, all four children had comorbidities: Child 2 impulse control disorder, Child 9 impulse control disorder and attention deficit hyperactivity disorder, Child 18 attention deficit hyperactivity disorder, and Child 20 epilepsy. In addition, the differences in Child 2 may be explained because the child was only 6 years old and very insecure without the presence of the mother. Notably, Child 20 has below average language skills, which may have led to the differences despite sufficient language comprehension.

When looking at the interactions across the entire warm-up task, the results are close to equivalence between the conditions. Overall, the data clearly indicates that the children with ASD interacted similarly in different conditions, despite the individual differences noted. It can therefore be assumed that a digital application with an avatar can induce similar behavior in children, as would be the case in a real-life conversation with an experimenter. Our findings support the premise of the *rich-get-richer hypothesis* (Valkenburg & Peter, 2007) that young individuals show continuity in social interaction across different environments. Furthermore, the results of this study do not indicate that mediated communication is more beneficial than face-to-face communication for children with ASD.

Limitations

The limitations of the study are the small sample size, which leads to low statistical power, and the subject of the study itself. Our study design is unique: first, because of the within-subject design, and second, because of the equivalence test. In a classical hypothesis test, an attempt is made to reject the null hypothesis of equality (Lakens et al., 2018). However, we were convinced that the research question of this paper could be analyzed only through a within-subject comparison and an equivalence test. Due to the small sample size and the desire for equivalence, the data show no to minimal variance. Therefore, the interpretation of the statistical results should be interpreted with caution. The low to no variance is due to the presence of ceiling effects. For example, Figs. 3 and 4 show that most of the children in each condition always responded verbally and conversationally, indicating a high level of social competence. As we are analyzing the media equation of the interaction between conditions within each child and have also assumed equality, it was to be expected that there would be a lack of variance. Notably, the coding of the residual category is included in the analysis, which can be seen as a potential limitation. As shown in Figs. 3 and 4, and in Table 2, this category is often coded, which may affect the results. However, it should be noted that this category is not equivalent to missing values and was therefore included in the analysis. Furthermore, children's pragmatic abilities and related deficits are not taken into account, although individuals with ASD show pragmatic abnormalities (Eberhardt-Juchem, 2023). It would therefore be desirable to investigate the influence of pragmatic skills on interaction. A comparison with a control group in terms of ASD symptoms would also be of clinical interest. However, this does not contribute to the research question of the current study and has therefore been omitted.

Research Implications

The results of this study have several implications for further research. On the one hand, the results show a significant equivalence between the conditions (media equation), so that it can be assumed that the participating children behave in the same way in a digital environment as they do in a real environment. However, with a sample size of only 20 children, this requires further validation. Therefore, the sample size in this design should be increased. In addition, further analysis should also be carried out using other statistical analysis methods, such as the TOST bootstrap. The TOST bootstrap is also suitable for small samples, has minimal assumptions, and is best used when precise confidence intervals are important (Caldwell, 2025). In addition, further studies should replicate the design with a non-verbal interaction task and include children with ASD who communicate non-verbally to determine whether media equation can also be detected. In conclusion, the results of this study provide a positive outlook on the possibility of digital screening for ASD, so the next step should be to test whether specific tablet-based tasks can discriminate between children with and without ASD. To this end, children with and without ASD should perform various tablet-based tasks that have been shown to discriminate in other research, and this should be evaluated in terms of sensitivity and specificity.

Conclusion

Considering the present findings and despite the limitations of this research, we conclude that children with ASD interact similarly in digital conditions as they do in face-to-face situations. For the future vision of a digital screening tool, it is important that children with ASD do not show different behaviors in a digital environment, as is the case in the study by Kellems et al. (2023), where children show greater social engagement when interacting with an avatar than when interacting with a human. It is important that the children show (almost) the same behavior in the digital environment in order to identify ASD in a digital screening tool. On the basis of this study, it can be assumed that computer-mediated communication is very similar to face-to-face communication in children with ASD. Therefore, in this proof-of-concept approach, the media equation is present in children with ASD. This means that the participating children with ASD can be expected to exhibit ASD-related behaviors in the digital environment as they would in person. Further validation of the media equation theory for children with ASD is needed, and future research is needed to determine whether ASD-related behaviors can be reliably stratified in an application. To do this, different tasks need to be tested and evaluated in the development process. In conclusion, further research is still needed to determine whether an app can be used as a screening tool for ASD.

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Author Contribution Author 1: Conceptualization (support); Data analysis (lead); Investigation (lead); Writing– original draft (lead); Writing - review and editing (equal). Author 2: Conceptualization (lead); writing– review and editing (equal). Author 3: Conceptualization (lead); writing– review and editing (equal).

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Data Availability Data will be shared on request to the corresponding author with permission of the entire consortium (Fraunhofer Institute for Digital Media Technology; KIZMO GmbH; SpeechCare GmbH; University of Leipzig Medical Center; TU Dortmund University).

Declarations

Ethical Approval The study involving human participants was reviewed and approved by the Ethics Committee, Department of Rehabilitation Sciences, TU Dortmund University (GEKTUDO_2022_45). Written informed consent to participate in this study was provided by the participant's legal guardian/next of kin.

Conflict of interest The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Appendix D: Study IV

Pliska, L., Neitzel, I., Buschermöhle, M., Kunina-Habenicht, O., & Ritterfeld, U. (2026). Digital screening of children with ASD: Diagnostic accuracy of emotion recognition and visual preference tasks. *BMC Psychiatry, 26*(75). *https://doi.org/10.1186/s12888-025-07725-z*

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Digital screening of children with ASD: diagnostic accuracy of emotion recognition and visual preference tasks

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Abstract

Background In Germany, there is a need to improve care for suspected autism spectrum disorder (ASD) cases, as the time between parents' initial suspicion and an official clinical diagnosis can reach three years. New technologies for digital screening promise relief in addressing children's difficulties in recognizing emotions and social attention. This study investigated the diagnostic validity of tablet-based screening to differentiate between children with and without ASD via emotion recognition and visual preference tasks involving prior calibration.

Method This study involved 24 boys with ASD and a matched control group of 24 typically developing (TD) boys aged 6–11 years. Mixed logistic models were applied for the emotion recognition task, while mixed linear models were used for the visual preference task, along with decision trees for both tasks.

Results The results indicate significant group differences in recognizing the emotion "fear" and naming an example for "sadness". The emotion recognition of fear and sadness was relevant to the decision tree to differentiate between the groups, with an accuracy of 81.25%, a sensitivity of 91.67%, and a specificity of 70.83%. For the visual preference task, no significant group differences were found between groups; however, significant differences emerged between social and non-social image stimuli. Gaze fixation and gaze changes in video stimuli were relevant to the decision tree to differentiate between the groups. The accuracy was 81.25%, with a sensitivity of 70.83% and specificity of 91.67%.

Conclusion Overall, this study suggests that automated digital screening might provide support and relief to families and clinicians, as it can distinguish between children with and without ASD using a combination of selected emotion recognition and visual preference tasks.

Clinical trial number Not applicable.

Keywords Autism spectrum disorder, Emotion recognition, Visual preference, Digital screening, Diagnostic accuracy, Sensitivity, Specificity

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Introduction

Autism spectrum disorder (ASD) is a neurodevelopmental disorder [1] with a worldwide prevalence of approximately 1 in 100 children [2]. More recent data from the Autism and Developmental Disabilities Monitoring Network shows that, in 2022, around 1 in 31 eight-year-olds had ASD [3]. Although the clinical presentation of ASD is heterogeneous and symptoms vary from person to person and are multifaceted [4], the main symptoms of ASD are long-term deficits in social interaction and communication as well as restricted interests and repetitive behaviors [1]. The impairment of social interaction includes non-verbal communication behaviors, including the ability to read and signal emotions [5]. Thus, people with ASD may have difficulties recognizing faces and emotions [6]. For example, a meta-analysis by Uljarevic and Hamilton [7] reported difficulties with emotion recognition in individuals with ASD, with a mean effect size of 0.80 (0.41 when corrected for publication bias). Another symptom is the so-called abnormal social attention of children with ASD [8, 9], which can be used to understand deficits in social interaction [9]. Abnormal social attention refers to the visual preference for non-social stimuli over social stimuli [9]. For example, a meta-analysis by Chita-Tegmark [10] showed that individuals with ASD spend less time attending to social stimuli than typically developing (TD) individuals do, with a mean effect size of 0.55.

Existing diagnostic tools have focused on deviated patterns of social communication and interaction to diagnose ASD [11]. However, the process of diagnosing ASD is characterized by delays and long waiting times. It can take up to three years from the onset of symptoms and the parents' initial concerns to obtain a diagnosis [12]. In Germany, for example, parents typically report concerns about their child's behavior around the age of two years, yet the average age of the first diagnosis is 6;6 years, when most children are already attending school [13]. This significant delay can be explained by two challenges. First, the rapidly increasing demand for early detection and diagnosis may contribute to delayed ASD diagnoses, as this time-consuming process relies on a limited number of well-trained practitioners [14]. In addition, the increasing prevalence of ASD [14] has put extra demand on clinicians, with this increase being likely a result of greater public awareness and progress in case detection through significant improvements in early identification. Although the final diagnosis using gold standard measures cannot be replaced by an automated diagnostic tool, an early screening of the likelihood of ASD in a child could reduce the workload of clinicians by decreasing the number of children on the waiting list who are no longer suspected of having ASD after screening. Second, the symptoms of ASD are highly heterogeneous, which complicates the diagnostic process [15]. Such delays have detrimental effects on individuals and families seeking proper diagnoses [12]. Not only do they create uncertainty for the entire family [16], they also delay the initiation of family support and child therapy [17]. Given that an early start to intervention has been shown to lead to better developmental outcomes, this delay may result in additional adverse effects [16, 18]. This clearly demonstrates the need for improved forms of care for suspected cases of ASD – not only, but especially in Germany (see [13]).

Digital technologies have the potential to support the screening and diagnostic process in ASD [19, 20], making clinical decisions more objective and reducing necessary resources [21]. Digital screening can be an effective method for detecting symptoms of ASD; it can be conducted by non-specialists and may take place in the child's natural environment [19, 22]. Digital technologies have already been used in a number of studies to identify people at risk of ASD effectively (overview in [22]). One example is the early autism screening tool (EAST), an interactive tablet-based app that assesses preschool children in Pakistan on how they relate to people, imitation, motor skills, visual, and intellectual responses through play-based activities in home, school, or clinical settings [23]. Another example is ASDetect, a free mobile application based on the Social Attention and Communication Surveillance (SACS) tool, which assesses behavioral markers of ASD from 12 to 24 months of age [24]. In addition, a web-based online screening tool called the Web Italian Network for Autism Spectrum Disorder (WIN4ASD), an innovative web application for pediatricians, was developed in Italy [25]. Perochon et al. [26] reported on a digital autism screening application (app) that displays stimuli that elicit behavioral signs of ASD, quantified via computer vision and machine learning. Another current example is the German IDEAS project[1]. IDEAS stands for 'Identification of Autism Spectrum Disorder using speech and facial expression recognition'. This project involves developing a tablet-based digital screening tool (app). Since the gold standard instrument for diagnosing ASD (Autism Diagnostic Observation Schedule, Second Edition; ADOS-2; [27]) uses a combination of tasks due to the heterogeneity of ASD symptoms, this should also be taken into account in digital screening. Therefore, exploratory analyses are necessary to examine individual tasks that may discriminate between children with ASD and TD in combination. In this context, our study aims to investigate whether prototype tasks on emotion recognition and visual preference

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for this tablet-based screening can effectively discriminate between children with and without ASD. It is therefore necessary to check the diagnostic accuracy and combination of these two tasks.

Emotion recognition

Emotional impairment, including deficits in emotion recognition, has been proposed as a diagnostic criterion for ASD [28]. In general, emotion recognition refers to the attribution of emotional states by analyzing non-verbal cues, such as facial expressions [29]. Emotion recognition between the ages of 6 and 11 years is a predictor of well-being and social relationships [30]. However, the literature shows contradictory effects of emotion recognition in people with ASD [7].

For example, a study by Castelli [31] showed that children with ASD were just as proficient as TD children at recognizing all six basic emotions (fear, happiness, anger, sadness, disgust, surprise; [32]) from facial expressions. However, it should be noted that, at the beginning, emotion recognition was practiced and describing the emotion was also considered correct (for example, for the emotion sadness, it was also considered correct if the child said 'crying'), which is why no difference was found. In an untimed condition, in which stimuli were presented until the participant responded, Nagy et al. [33] also showed that children with and without ASD were equally accurate in identifying emotions. Only in the timed condition, when stimuli were shown for a maximum of 1,200 ms, were the children with ASD less accurate at identifying anger and surprise [33]. In the study by Tanaka et al. [34], the children were shown images expressing an emotion with different emotion labels until one label was selected. This may explain why their study found no differences in basic emotion recognition between children with and without ASD, except for anger [34]. In addition, the results of a meta-analysis by Icht et al. [35] also suggest that people with ASD do not differ from TD individuals in the recognition of simple prosodic emotions such as sadness and happiness.

In contrast, other studies have shown that people with ASD display poorer emotion recognition than TD individuals do [36] and that emotion recognition is poorer in individuals with ASD than in individuals in other clinical groups [37]. Meta-analyses by Uljarevic and Hamilton [7], by Lozier et al. [6] and by Yeung [37] analyzed emotion recognition in individuals with ASD and reported a significant impairment in the recognition of basic emotions in individuals with ASD. However, recognition of happiness was only slightly impaired in individuals with ASD, and fear was only slightly less frequently recognized correctly than happiness [7]. In a study by Evers et al. [38], in addition to some emotion-specific impairments in children with ASD aged 6–14 years, a generally poorer performance in emotion recognition compared with TD children was described. However, the participants showed a preference for the selection of certain emotion labels. Fear was selected more often by children with ASD than TD children. This could also explain the better performance of children with ASD in identifying fear. As a result of this preference, the data were corrected for response bias. Afterwards, the results no longer show any emotion-specific impairment but still show an overall lower emotion recognition performance in individuals with ASD [38]. Compared with the findings of Evers et al. [38], a synthesis of data from 72 papers by Leung et al. [39] demonstrated that the accuracy of emotion recognition is generally impaired in people with ASD but also that people with ASD display longer response times for a subset of emotions (anger, fear, sadness vs. performance across all six basic emotions). Findings by Griffiths et al. [40] provide further evidence of an impairment in the recognition of basic emotions in children and adolescents with ASD. For all basic emotions, the difference in emotion recognition is significant. One reason for these differences could be the sex ratio between the groups (ASD group predominantly boys, control group balanced sex ratio; [40]), as females have been shown to perform better on emotion recognition tasks [41]. However, the accuracy of recognizing the emotion "fear" was low in both groups, which can be attributed to an overall poorer recognition of this emotion in both groups [40]. This contradicts the reported preference for fear reported by Evers et al. [38].

Song and Hakoda [42] also addressed the recognition thresholds at which children with and without ASD correctly identified emotional expressions that changed from a neutral expression to the corresponding basic emotion. Overall, they reported that the different emotions had different recognition thresholds in both groups. However, compared with TD children, children with ASD generally require a significantly greater intensity of stimuli to correctly identify anger, disgust, and fear. These results suggest a selective impairment rather than a general impairment in the recognition of basic emotions [42].

There is no difference in emotion recognition between older children with ASD and adults with ASD [43]. In addition, between the ages of 8 and 12 years, children with ASD appear to catch up with TD children at this age, so that by the age of 12 years, children with and without ASD no longer differ in the recognition of basic emotions, and this remains comparable to adolescence. Findings by Rump et al. [43] show, on the one hand, that children with ASD between the ages of 5 and 7 years recognized some emotions less accurately than TD children did and, on the other hand, that children with ASD recognized emotions differently in general. TD children

were significantly better at recognizing fear and anger according to the study results. However, there was no significant difference in the recognition of happiness and sadness. Overall, happiness was the easiest emotion for both groups to recognize, whereas children with ASD had significantly more difficulties recognizing anger and fear [43].

However, the ability to recognize one's own emotions (emotional self-awareness) may be essential for recognizing the emotions of others (cf [44]). In addition to deficits in emotion recognition, people with ASD are described as having difficulties with emotional self-awareness, i.e., recognizing and understanding their own feelings [45]. In a meta-analysis by Huggins et al. [45], 32 out of 41 studies reported significantly lower emotional self-awareness in people with ASD. Meta-analyses of self-report measures have shown that people with ASD have significantly impaired overall emotional self-awareness (d = 1.16). However, concerning age groups, differences in emotional self-awareness appear only in adolescents (d = 0.63; 12 years and younger: d = 0.03) and increase with age (d = 1.16 to d = 1.58; 45).

In summary, research shows contradictory results as to whether children with ASD perform poorer at recognizing basic emotions than children without ASD [7, 31, 36, 39, 40]. Given the inconsistent results regarding emotion recognition, it is important to examine whether this task can distinguish between children with and without ASD in a digital setting. It would also be interesting to establish whether only certain emotions can be used for this purpose. There is evidence that differences in emotion recognition depend on the emotion [38, 43], and it has been described that children with ASD have problems with emotional self-awareness [45]. An emotion recognition task involving the description of a situation in which an emotion is experienced may thus be a more decisive task for screening to differentiate ASD from TD individuals. Therefore, we investigate the emotion recognition task in an appropriate digital task setting that includes two parts. The first part of this study addresses the following research question:

1. Can an emotion recognition task (comprising emotion recognition and situation description) be used to distinguish between children with and without ASD?

Visual preference

One of the most reliable measures for discriminating between the ASD and TD groups was a reduced preference for social stimuli [22]. Such a task can be implemented via readily available technology (e.g., tablets) in conjunction with objective performance measurements, making it usable by non-specialists [22]. To measure children's attentional preferences for social versus non-social stimuli, a promising screening approach is to use eye-tracking technology [46]. Eye-tracking technologies can be considered complementary to traditional screening measures [19]. A meta-analysis by Chita-Tegmark [10] examined social attention in studies using eye-tracking to compare people with and without ASD and evaluated factors that might influence effect sizes. The results show that, with a mean effect size of 0.55, people with ASD spend significantly less time paying attention to social stimuli than TD people do. Social attention[2] is most affected in people with ASD when stimuli have high social content (more than one person; [10]).

In a study by Wang et al. [47], human eyes and high-/low-autism-interest objects were presented simultaneously to children. Participants with and without ASD showed reduced social preference when an image of human eyes was paired with objects attributed to high ASD interest (cars; [47]). However, it would be oversimplifying to assume that all individuals with ASD should have a special interest in a particular object. Therefore, these designs are debatable and can be seen as limitations of these studies. Nevertheless, findings by Ambarchi et al. [8] suggest atypical attentional patterns in social and non-social domains in ASD, with ASD interests playing a reduced role. Ambarchi et al. [8] reported that children with ASD are significantly slower in prioritizing faces than TD children are. Similarly, a study by Goold et al. [48] revealed that adults with ASD-associated traits show a faster saccadic response to shift attention away from a face and to recognize the non-social target than adults with low levels of ASD-associated traits do. In both studies [8, 48], faces displaying different emotional expressions were used instead of neutral faces. However, Chawarska et al. [49] demonstrated that six-month-old infants who were later diagnosed with ASD in childhood paid significantly less attention to a social scene and spent significantly less time looking at the actress in general and at her neutral face in particular while watching the scene, compared to control groups.

Crawford et al. [50] investigated whether attentional allocation was influenced by potential threats, i.e., whether stimuli were moving toward or by an observer. The results indicated that adolescents with ASD had a shorter gaze duration for social videos compared to non-social videos only when the stimuli were moving toward them [50]. In addition, an automated eye-tracking task by Strathearn et al. [51] showed that children and adolescents with ASD had a stronger gaze preference for visually organized and structured images than TD controls

[2] Social attention refers to individuals paying preferential attention to social stimuli, whereas 'visual preference' is a general term for the preference of either social or non-social stimuli.

did. Similarly, a study by Cardon and Azuma [52] noted that the visual attention of children with ASD can be influenced by the type of presentation, as the children showed a visual preference for video presentations over live presentations. However, the result was also evident in the TD group, and it should be noted that both groups consisted of only nine children each.

A study by Król and Król [53] revealed that the sequence of eye movements (saccades) of participants with ASD was significantly greater when they responded to non-social images and significantly lower when they responded to social images than TD individuals did. In addition, the sequence of eye movements in participants with ASD was more similar to that in TD participants when they responded to non-social images and less similar when they responded to social images. The results suggest that individuals with ASD have an attentional bias for non-social stimuli and a weaker preference for social stimuli [53].

In terms of visual preference in children with ASD, Kou et al. [54] addressed three different stimulus paradigms. The first paradigm included dancing people versus dynamic geometric images, which was the most effective scenario. In this paradigm, children with ASD showed a significantly greater preference for dynamic geometric images than for dancing people. A study by Robain et al. [55], with a similar design to the first paradigm, supported the findings. Furthermore, visual preference in 4- to 6-year-old children with ASD appears to be modulated by the type of visual stimulus [56]. Thus, the results of a study by Shi et al. [56] show that, in comparison with TD children, children with ASD pay less attention to stimuli with two or more children playing together than to stimuli with only one child. The second paradigm involves the biological motion of points of light versus non-biological motion of points of light [54]. Similar to the results of Kou et al. [54], Kaliukhovich et al. [57] reported that participants with ASD spent significantly less time looking at presented stimuli than controls did and showed less preference for biological motion. For the third paradigm – a toy alone vs. a child playing with that toy – group differences were also found between the ASD group and the TD group [54].

Chevallier et al. [58] investigated the social attention of children with ASD compared with that of TD children via three different tasks: (1) static visual exploration (images of people vs. images of objects), (2) dynamic visual exploration (videos of people vs. videos of objects), and (3) interactive visual exploration (videos of children playing with objects). Significant differences concerning social attention in the ASD group were exclusively found in the third task (interactive visual exploration). Reduced social attention for children with ASD was evident here [58]. However, a study by Cilia et al. [59] showed that, in addition to dynamic stimuli, static stimuli are also relevant for differentiating between children with ASD and TD children.

Pliska et al. [60] investigated visual preference in boys aged 6–11 years with and without ASD in terms of stimulus presentation (images vs. video) and stimulus complexity (one child playing alone vs. two children playing together). This study revealed no significant differences in visual preference. Neither the format of stimulus presentation nor the different levels of stimulus complexity had any effect on visual preference. However, participants with ASD had already received ASD-specific therapy, which may have had a significant impact on the results [60]. On the other hand, a study by Fischer et al. [61] also found no differences in visual attention between children with ASD and TD children aged 5–12 years. Matyjek et al. [62] conducted a study of visual preference for social and geometric motion in adults with and without ASD. The difference between the adults was in the duration of fixation. Adults without ASD spent more time looking at social stimuli than at geometric movements. In contrast, there were no differences in fixation between social and geometric stimuli in adults with ASD [62]. Overall, the findings of a study by Matyjek et al. [62] suggest that the decisive aspect is not whether children with ASD look at non-social stimuli more than do TD children, which has been the focus of previous studies [9, 54, 63, 64], but whether there is a difference in preference between social and non-social stimuli for TD children and no difference in preference for children with ASD. Overall, it can therefore be assumed that there are differences in visual preferences between people with and without ASD, but that these may vary by age group (infants, children, adults). Therefore, the second part of this study addresses the following research question:

2. Can a visual preference task be used to distinguish between children with and without ASD?

Method

Participants

A total sample of 48 children aged 6–11 years was included in the current study. Although the long-term goal of this study is to contribute to the early identification of ASD, the age range of 6–11 years was chosen for an initial exploratory investigation. For this initial investigation, it is important to ensure that the children in the ASD group have a confirmed ASD diagnosis, which on average is achieved at 6;6 years of age in Germany [13]. Data for this study were collected from February 2023 to March 2025. Participants were recruited through various autism therapy centers in the area, open all-day schools, and private contacts. All participating families were informed in writing about the purpose and procedure of

the study and they provided written consent. The children were verbally informed again at the testing appointment and gave their consent. In addition, a positive ethics vote for the study was obtained in advance (GEKTUDO_2022_45). This study was not pre-registered. The study design included two groups: (1) the ASD group and (2) the TD group. The two groups were matched for children's age, sex, and parents' level of education. The prerequisites for participation in the study were that the children could speak fluently and appropriately for their age (as assessed by their parents in the TD group and ASD therapists in the ASD group), and that they had adequate hearing. Most parents in both groups hold a high school diploma (median score). Given that the ratio of males to females diagnosed with ASD is approximately 3:1 [65] and that the symptoms of females are thought to be qualitatively different from those of boys [66], only boys were included in the study for comparability.

The ASD group consisted of 24 boys who had previously been officially diagnosed with ASD and exhibited no intellectual impairment. Of those boys, 20 boys had already received ASD-specific therapy. In Germany, a diagnosis of ASD is a prerequisite for receiving ASD-specific therapy. ASD is typically diagnosed using a combination of the Autism Diagnostic Observation Schedule and the revised Autism Diagnostic Interview [67] according to the ICD-10 classification system. The children with ASD were, on average, 112.17 months (9;4 years) old (*SD* = 21.65) and had received, on average, 13.67 months (*SD* = 11.67; range = 0–48 months) of therapy. The German version of the Social Communication Questionnaire (FSK; [68]) was used to confirm that the children in the TD group were below the cut-off score for suspected ASD, while those in the ASD group were above it due to the ASD-specific support they had already received. The FSK is a screening instrument that follows the diagnostic guidelines of the ICD-10 [68]. All children in the ASD group had a diagnosis of ASD, although 8 out of 24 children no longer met the screening threshold for a suspected diagnosis of ASD (≥ 16) based on the FSK [68] – completed by parents – at the time of participation in the study. The duration of therapy was negatively correlated with the FSK score (r = -.23), but this correlation was not significant (p = .323). This result suggests that the longer children receive ASD-specific support, the fewer symptoms of ASD their parents perceive, which is an essential goal of such support or therapy programs. Five children reported attention-deficit (hyperactivity) disorder (AD(H)D) in addition to ASD, and none of them were taking medication during the tasks. AD(H)D is often comorbid with ASD [69]. One child also has impulse control and a reactive attachment disorder. Two other children displayed an impulse control disorder as well as ASD, and one of them had additional verbal developmental dyspraxia. Three children had tic disorders, and one also had anxiety and attachment disorder. Tics were not exhibited during the task. In addition, one child had epilepsy, one had a sleep disorder, and another had a perceptual disorder. Information about additional disorders in addition to ASD is based solely on information provided by the parents. Six children wore glasses.

The TD group consisted of 24 TD boys aged 109.96 months on average (*SD* = 19.78), which was equal to 9 years and 2 months. All children in the TD group scored below the FSK screening threshold for suspected ASD (< 16). The parents of this group reported that two children had ADHD, one had a reading and spelling disorder and one had a tic disorder. Three children wore glasses.

Measures

This study was part of the IDEAS research project, which aimed to develop an automated digital screening for ASD. The tasks were completed by all the participants in two different conditions: with a human experimenter and with a pre-recorded avatar experimenter (details in [70]). The results of a first analysis by Pliska et al. [71] suggest that children with ASD interact in the same way (significant equivalence) regardless of the experimenter's digital mediation, and there is no need to distinguish between the two conditions in the analysis. The same is assumed for the control group, although this has not been empirically tested. The tasks were presented to the participating children on a 25-inch screen positioned approximately 60 cm in front of them. The children who needed glasses wore them throughout the entire study.

Emotion recognition task

The emotion recognition task used pictures of children with facial expressions from the Child Emotion Facial Expression Set by Negrão et al. [30]. Five pictures of a girl showing the following basic emotions were used: happiness, anger, sadness, disgust, and fear. The test administrators selected this child's pictures because they judged that the child in the stimulus set most clearly expressed the emotions depicted in these pictures. This selection was made independently of gender.

The emotion of surprise was excluded from the study because previous studies (e.g [72, 73]). have called into question whether surprise is a basic emotion. The participants were always shown one picture on a screen with the question "How does the child feel?". After the response of the participants to this question, the experimenter named the emotion and asked when the participant had experienced that emotion before, e.g., in the case of happiness: "This is happiness. The child is happy. When are you happy?". In the following, the participants should describe a situation in which they experienced this emotion.

Visual preference task

The visual preference task consisted of different stimulus presentation formats (images vs. videos) and different levels of stimulus complexity (one person vs. two people). The participants saw pairs of social and non-social stimuli side by side on a screen. It was systematically counterbalanced, whether the social stimulus or the non-social stimulus was shown on the left or right side of the screen. The participants saw a total of six pairs of approximately 10s in duration each, with the social image showing one or more people playing and the non-social image showing images of the universe (galaxies and stars). In addition, four pairs of videos of approximately 18s were used, with the social video showing a man or woman making dynamic grimaces and the non-social video showing dynamic geometric shapes. This video material stems from a study by Polzer et al. [74]. During the presentation of the image and video pairs, eye movements (i.e., eye position and gaze direction) were captured and recorded with up to six frames per second via a customized native iOS app (KIZMO Face-Analyzer). The storage rate of six frames per second was selected because it was important to record where participants looked for longer periods of time (several seconds), while short-term saccades were irrelevant. This app was developed by KIZMO GmbH for use on iPads, specifically for this task, and it was developed based on a person wearing glasses. The iPad was placed behind the screen, with the camera to the left of the screen during the task. Prior to the visual preference task, a calibration was performed to relate eye movements to gaze direction in screen coordinates.

Data analysis

R Studio version 4.4.2 [75] was used for data analysis. The 'lmerTest' package [76] was used for random effects models, the 'emmeans' package [77] was used for post-hoc tests, and the 'MuMIn' package [78] was used for variance components. Plots were generated via the "ggplot2" package [79]. The packages "rpart" [80], "party" [81], "ggparty" [82], and "rpart.plot" [83] were used to calculate accuracy, sensitivity, and specificity and to plot the decision trees. A significance level of $p < .05$ was used in all calculations.

Emotion recognition task

Logistic mixed models were used to analyze the emotion task. The dependent variable was once emotion recognition, coded 0 for not recognizing the emotion and 1 for correctly recognizing the emotion, and once experienced emotion example, coded 0 for no specific example and 1 for a specific example. The fixed effects were group, emotion, and the interaction of the two, and the random effects were child ID. Post-hoc tests were performed with Bonferroni correction.

To test whether the length of therapy had an effect on the dependent variable in relation to emotions, models were also created for the ASD group. Decision trees were computed with the dependent variable "group" (ASD and TD) and potential predictors of recognition of happiness, of anger, of sadness, of disgust, and of fear, as well as naming a specific example of happiness, of anger, of sadness, of disgust, and of fear. Therefore, the Gini index, a common measure of inequality [84] and a popular attribute selection measure for decision trees [85], was used.

Visual preference task

Based on the previous calibration, the raw data from the AR kit is converted into screen coordinates. These transformed viewpoints are then used during measurement and analysis. The relative percentage of frames recorded in the left and right image/video recordings (social or non-social) was analyzed via MATLAB [86]. On the basis of presentation (social or non-social), the percentage of frames per medium (image or video) was then summed and averaged. In addition, the number of gaze changes between the left and right stimuli was recorded.

Linear mixed models were used to analyze the visual preference task. The dependent variable was gaze fixation duration, and the main effects and interactions were (1) group, presentation, and medium; (2) medium, presentation, and FSK; and (3) group, presentation, and age. The random effects were child ID and stimulus pairs. In another model, the dependent variable was the number of gaze changes, and the presentation was omitted from the fixed effects. Decision trees with the Gini index were computed with the dependent variable "group" (ASD and TD) and potential predictors of gaze fixation of social image, of non-social image, of social video, and of non-social video, as well as gaze change of medium image, and of medium video.

Comparison of decision trees

A decision tree for the emotion recognition task and a decision tree for the visual preference task were each cross-tabulated with the predictions. These results were then compared with those of the actual groups.

Results

Emotion recognition task

The two groups correctly recognized each emotion with varying frequency, except for happiness (see Supplement Figure S1). The emotion "happiness" was correctly recognized by 75% of the participants in both groups. Fear was correctly recognized by 17% of the TD group and by 65% of the ASD group. The emotion "disgust" was correctly recognized by 38% of the TD group and by 33% of the ASD group. Sadness was correctly recognized by 88% of the TD group and by 57% of the ASD group. The emotion

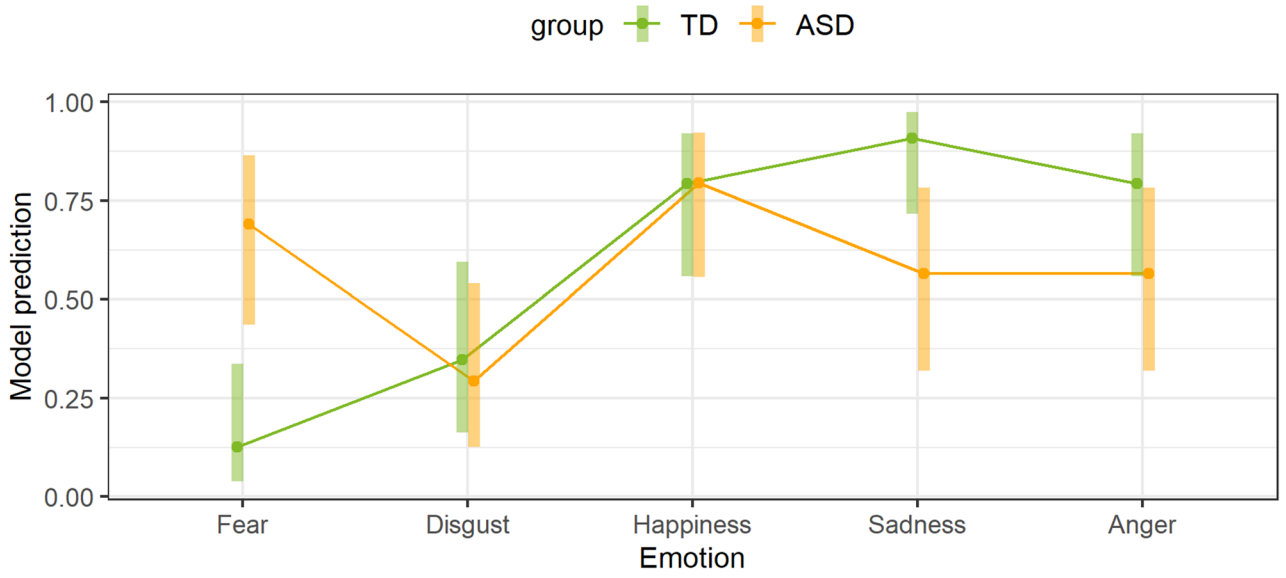

Fig. 1 Model of emotion recognition

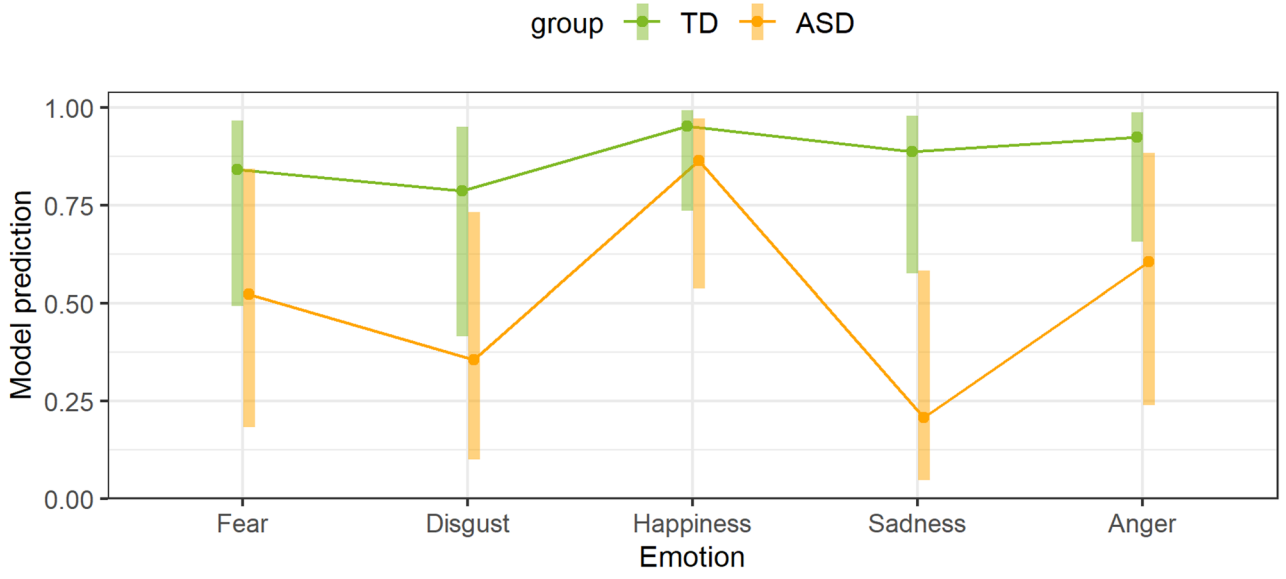

Fig. 2 Model of experienced emotion examples

"anger" was correctly recognized by 75% of the TD group and by 57% of the ASD group.

Figure 1 shows the model prediction for emotion recognition. When the ASD group was compared with the TD group, the model prediction was significant only for the emotion "fear" (OR = 15.41, 95%-KI: 1.72-138.14, $p = .007$). The model prediction for sadness had an OR of 0.13 (95%-KI: 0.01–1.24) and failed to reach significance ($p = .098$). In addition, the emotions of disgust (OR = 0.78, 95%-KI: 0.12–5.22, $p = 1$), happiness (OR = 1.01, 95%-KI: 0.13–7.85, $p = 1$) and anger (OR = 0.34, 95%-KI: 0.05–2.46, $p = .8$) were not significant.

The two groups mentioned a specific example of each emotion with varying frequency (see Supplement Figure S2). A specific example of the emotion "fear" was given by 71% of the TD group and by 50% of the ASD group. For disgust, 67% of the TD group and 42% of the ASD group were named a specific example. A specific example of the emotion "happiness" was given by 83% of the TD group and by 71% of the ASD group. For sadness, 75% of the TD group and 33% of the ASD group named a specific example. A specific example of the emotion "anger" was given by 79% of the TD group and by 54% of the ASD group.

Figure 2 shows the model prediction for the experienced emotion example. When the ASD group was compared with the TD group, the model prediction was significant only for the emotion "sadness" (OR = 0.03,

95%-KI: 0.001–0.85, $p = .034$). The emotions of fear (OR = 0.21, 95%-KI: 0.01–4.28, $p = .9$), disgust (OR = 0.15, 95%-KI: 0.01–3.09, $p = .529$), happiness (OR = 0.32, 95%-KI: 0.01–8.53, $p = 1$) and anger (OR = 0.13, 95%-KI: 0.01–2.99, $p = .462$) were not significant.

For both emotion recognition and experienced emotion, a model for the ASD group was used to test whether the length of therapy had an effect on emotion tasks. No significant effects were found for either emotion recognition or experienced emotion ($p > .05$).

The predictor variables age, recognition of the respective emotion, and the specific naming of a situation in which the respective emotion was experienced were included to predict the allocation to the respective group (TD or ASD). Only the emotion recognition of fear and the emotion recognition of sadness were relevant for classification (see Fig. 3). Of the children who correctly recognized the emotion "fear", just over 75% have ASD. Of those who did not recognize "fear" or "sadness", just under 75% have ASD. Among those who did not recognize "fear" but correctly recognized "sadness", over 87.5% are TD children. The accuracy was 81.25%, the sensitivity was 91.67%, and the specificity was 70.83%.

Visual preference task

The percentage fixation time varies according to group, medium, and presentation (see Supplement Figure S3). For the medium image, there are 144 observations per group and presentation because each child saw six images in each presentation. For video, there are 96 observations because each child saw four videos in each presentation. For the non-social image, the mean duration of gaze fixation was 29.97% ($SD = 17.73$) of the total frames in the TD group and 27.13% ($SD = 18.34$) in the ASD group. For social image, the mean duration of gaze fixation was 52.12% ($SD = 21.29$) in the TD group and 45.74% ($SD = 23.48$) in the ASD group. For the non-social video, the mean duration of gaze fixation was 31.21% ($SD = 25.47$) for the TD group and 36.33% ($SD = 26.48$) for the ASD group. For the social video, the mean duration of gaze fixation was 53.17% ($SD = 28.24$) for the TD group and 40.84% ($SD = 26.86$) for the ASD group.

The linear mixed model with gaze fixation duration as the dependent variable, main effects and interactions between (1) group, presentation, and medium, (2) medium, presentation, and FSK, and between (3) group, presentation, and age and simultaneous random variation between children and stimulus pairs showed no

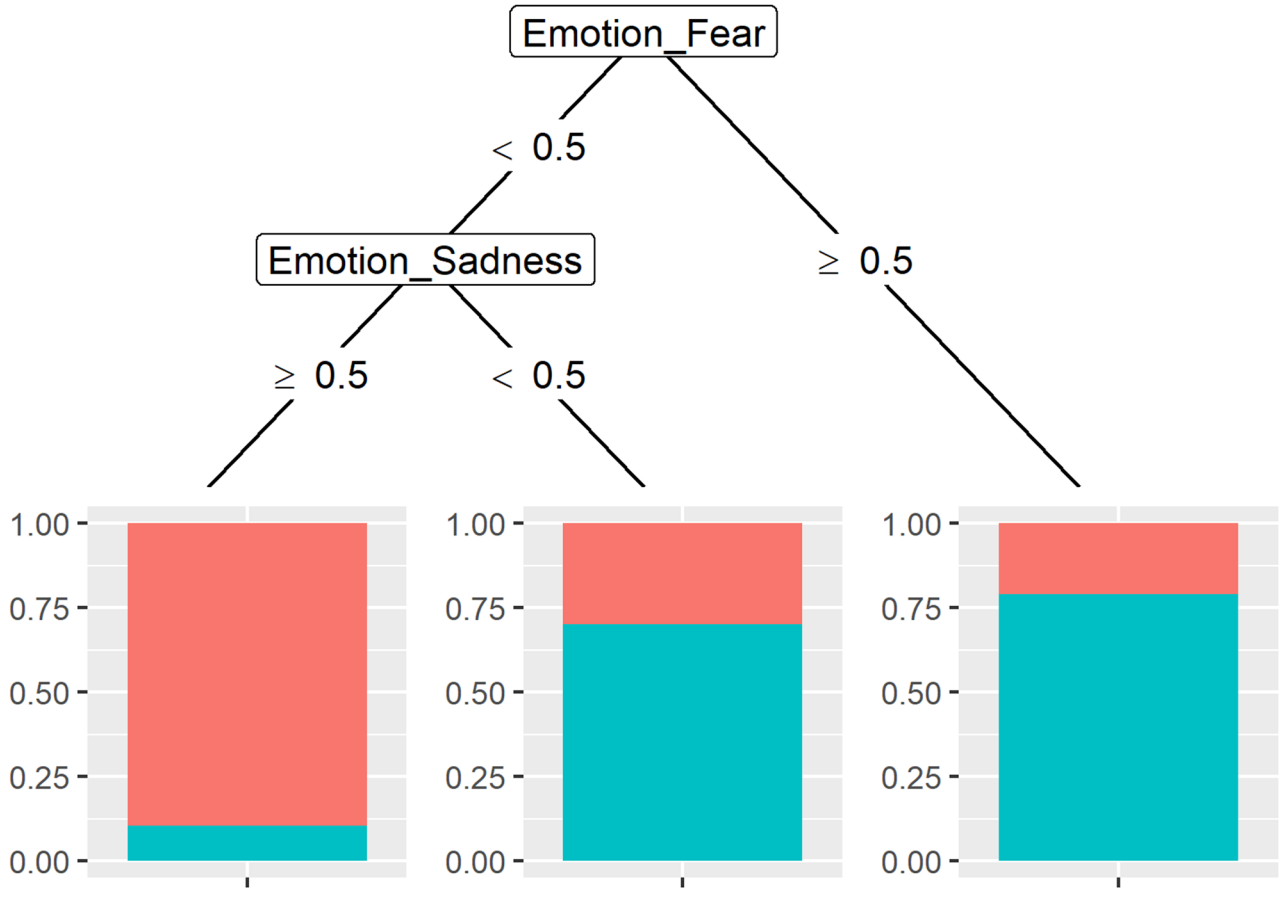

Fig. 3 Decision tree for the emotion task. *Note.* < 0.5 = Emotion not recognized, ≥ 0.5 = Emotion correctly recognized; red = TD, blue = ASD

significant results ($p > .05$). The post-hoc tests revealed no significant results for differences between groups for each combination of presentation and medium or for the medium for each combination of group and presentation ($p > .05$). In terms of differences in presentation for each combination of group and medium, there were no significant differences between the social and non-social only in the ASD group with the video as the medium ($p > .05$). Both the post-hoc test for differences between the presentation in the ASD group and the medium image (OR = 18.36, 95%-KI: 9.0-27.7, $p < .001$) and the post-hoc test for differences in the TD group and the medium image (OR = 23.55, 95%-KI: 15.06-32.0, $p < .001$) as well as the medium video (OR = 22.64, 95%-KI: 12.27-33.0, $p < .001$) were statistically significant. Figure 4 shows model predictions for the combination of group, presentation, and medium.

The number of gaze changes between groups varies according to the medium (see Supplement Figure S4). For the medium image, the mean number of gaze changes was 5.49 ($SD = 4.2$) in the TD group and 5.58 ($SD = 4.24$) in the ASD group. For the medium video, the mean number of gaze changes was 7.84 ($SD = 7.04$) in the TD group and 5.37 ($SD = 4.97$) in the ASD group.

Figure 5 shows the prediction model of the number of gaze changes for the combination of group and medium. The model prediction between the ASD and TD groups was not significant for either the medium image (OR = 0.57, 95%-KI: -2.55-3.70, $p = 1$) or the medium video (OR = -2.15, 95%-KI: -5.38-1.09, $p = .27$).

The model was also tested to determine whether there were any differences between each image and video pair. However, no significant results were found ($p > .05$). Therefore, only the predictor variables age, duration of gaze fixation on images and videos, social and non-social, and number of gaze changes on images and videos were used in the decision tree to predict group assignment (TD or ASD). Only the duration of gaze fixation on social videos and the number of gaze changes on videos were relevant for classification (see Fig. 6). Of the children in the group who had a relative duration of gaze fixation of more than 55% on the social video, just over 87.5% were TD children. Of those who had less than 55% of their gaze fixation on the social video and changed their gaze less than 16.5% on the medium video, just under 62.5% were TD children. This is also the case for those who changed their gaze on the medium video by more than 32.5%. Among children with less than 55% relative gaze fixation on the social video and a gaze change of between

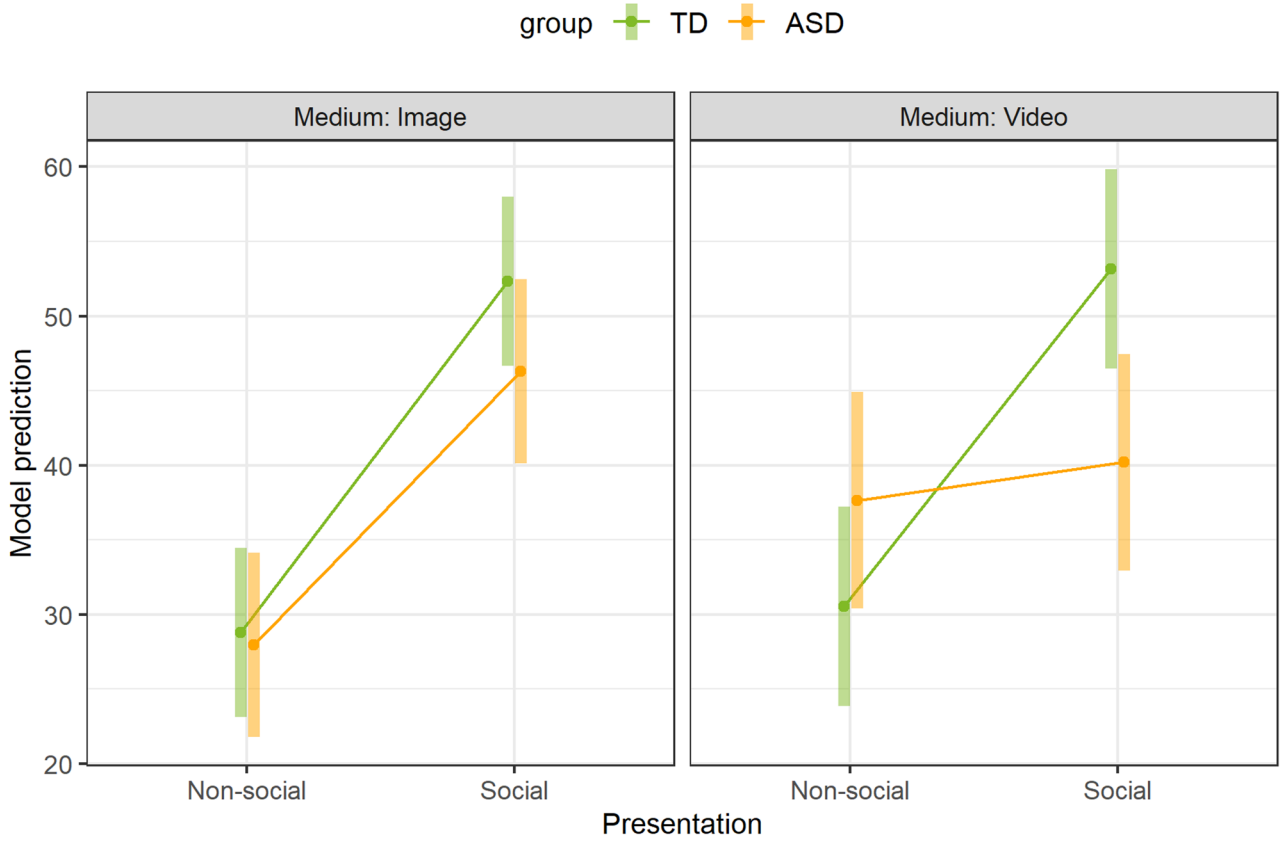

Fig. 4 Model predictions of the duration of gaze fixation for the combination of group, presentation, and medium

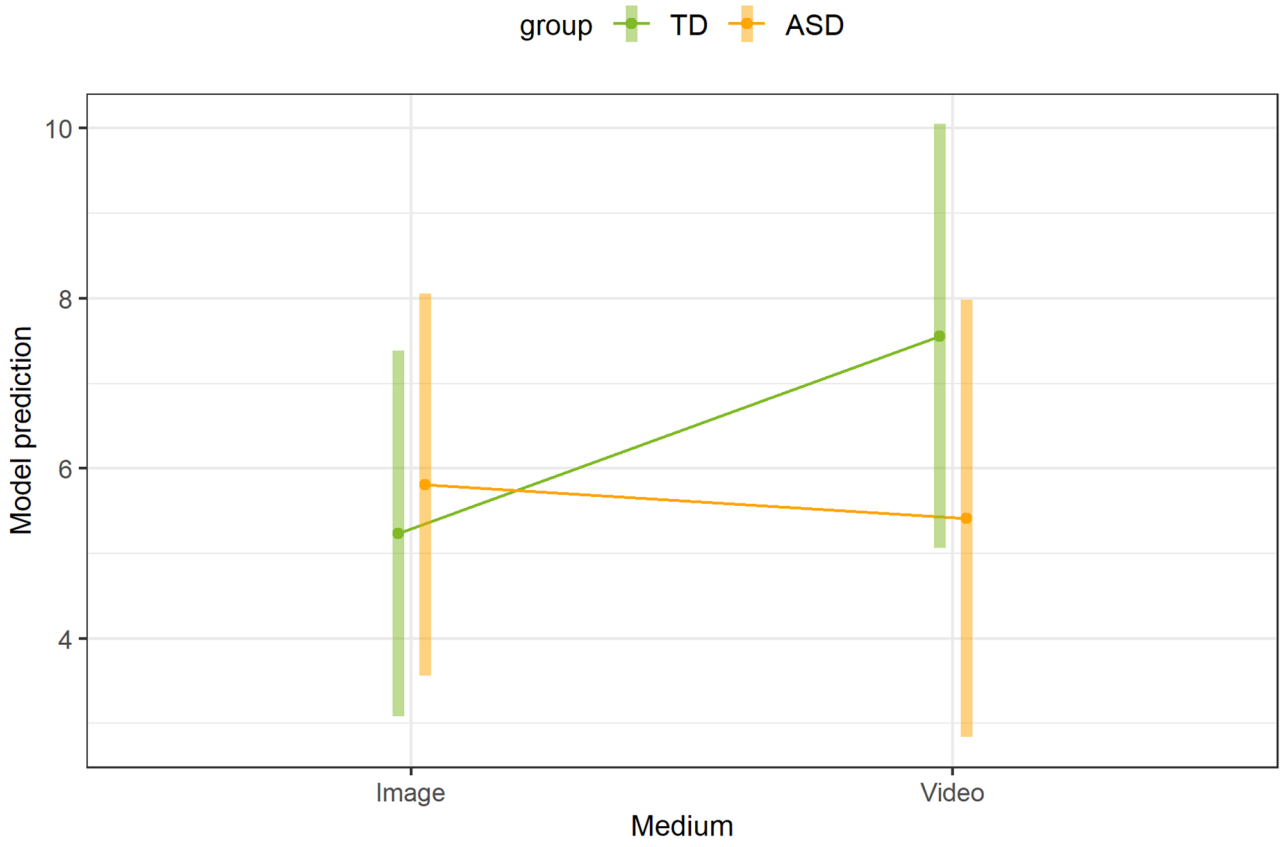

Fig. 5 Prediction model of the number of gaze changes for the combination of group and medium

16.5% and 32.5% on the medium video, just over 87.5% had ASD. The accuracy was 81.25%, the sensitivity was 70.83%, and the specificity was 91.67%.

Comparison of the decision trees

In the visual preference task, 29 children were predicted to be in the TD group, and 19 children were in the ASD group (see Table 1). For the emotion recognition task, the group assignment was conducted in the reverse order (see Table 1). When the two predictions were compared, 16 children were assigned to the TD group, and 16 children were assigned to the ASD group in both tasks. In the emotion recognition task, 13 children were assigned to the ASD group, who were assigned to the TD group in the visual preference task. In addition, three children were assigned to the ASD group in the visual preference task but were assigned to the TD group in the emotion recognition task.

The predictions for both tasks were then compared in relation to actual group membership (see Table 2). Out of the actual TD group of 24 children, 16 children were correctly classified by the predictions of both tasks. A further six children were correctly assigned to the TD group by the visual preference task but incorrectly assigned to the ASD group by the emotion recognition task. In contrast, one child was correctly assigned to the TD group by the emotion recognition task and incorrectly assigned to the ASD group by the visual preference task. One child was incorrectly assigned to the ASD group for both tasks. From the actual ASD group, which also consisted of 24 children, 15 children were correctly classified by the predictions of both tasks. Another two children were correctly assigned to the ASD group by the visual preference task but incorrectly assigned to the TD group by the emotion recognition task. In contrast, seven children were correctly assigned to the ASD group by the emotion recognition task and incorrectly assigned to the TD group by the visual preference task. Overall, there was no child who was incorrectly assigned to the TD group on both tasks.

In summary, the prediction on the emotion recognition task correctly classified 17 TD children and 22 children with ASD. Prediction on the visual preference task had correctly classified 22 children with ASD and 17 TD children.

Discussion

Due to the long waiting period and the associated uncertainty until a diagnosis of ASD is established, we investigated whether tablet-based digital screening with

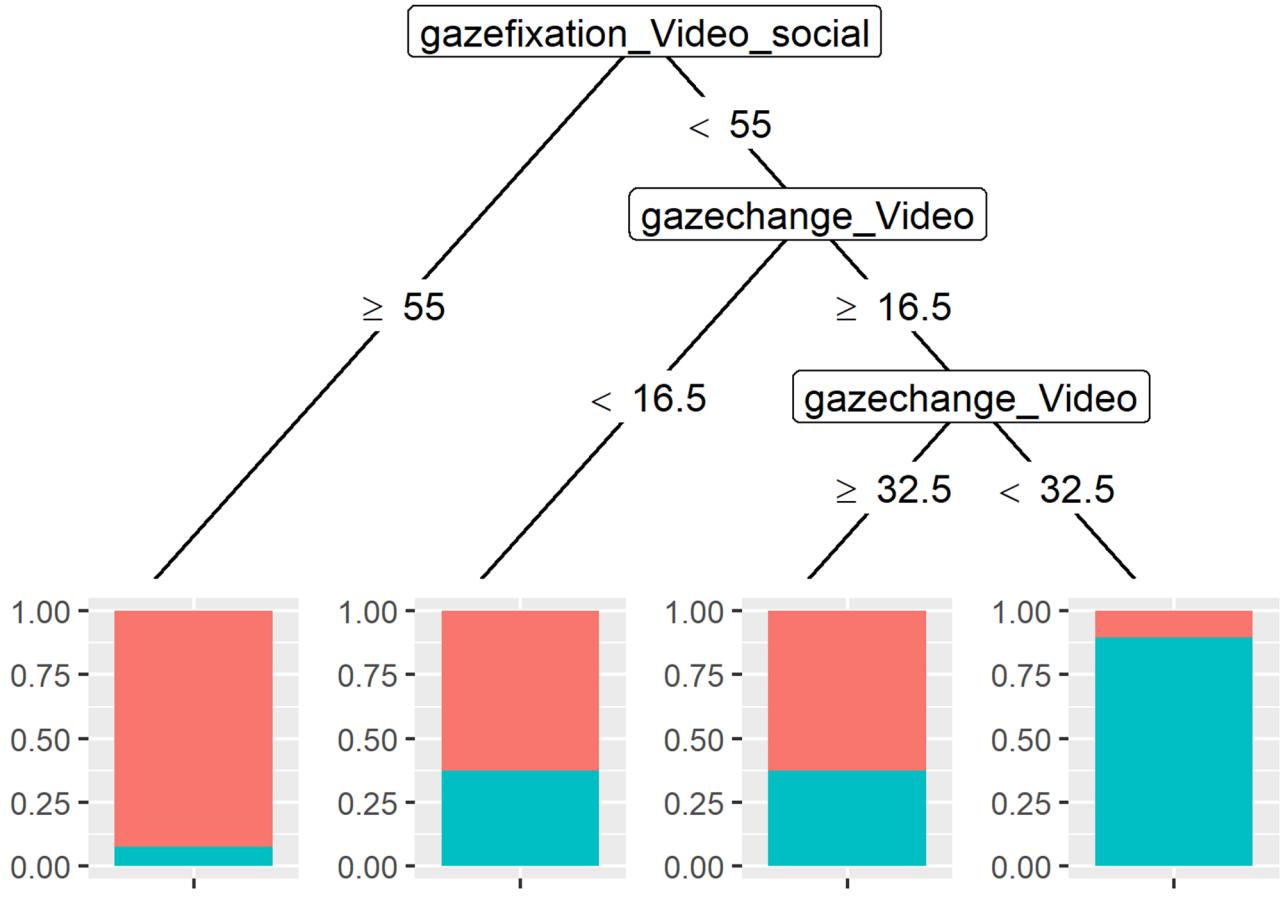

Fig. 6 Decision tree for the visual preference task. *Note.* red = TD, blue = ASD

Table 1 Correct allocation to the groups in relation to the two tasks

Emotion recognition task				Visual preference task			
		Allocation				Allocation	
		TD	ASD			TD	ASD
Correct allocation	TD	17	7	Correct allocation	TD	22	2
	ASD	2	22		ASD	7	17

Table 2 Comparison of the correct allocation to the groups in relation to the two tasks

TD				ASD			
		Emotion recognition task				Emotion recognition task	
		TD	ASD			TD	ASD
Visual preference task	TD	16	6	Visual preference task	TD	0	7
	ASD	1	1		ASD	2	15

emotion recognition and visual preference tasks could discriminate between children with ASD and children without ASD.

Emotion recognition task

Previous studies have shown mixed results concerning whether children with ASD are less accurate at recognizing basic emotions than TD children are [7, 31, 36]. Our results support the findings of Evers et al. [38] that children with ASD select the emotion "fear" more often than TD children do. However, while in Evers et al. study [38] dynamic facial expressions were used, in our study static facial expressions were used. However, the finding by Evers et al. [38] was no longer significant after correction for response bias. Our study indeed confirms a significant difference in the recognition of the emotion "fear". The children in the ASD group were significantly more likely to correctly identify the emotion "fear".

This contradicts the results of Griffiths et al. [40], who reported a generally low accuracy of emotion recognition for fear in both groups. In our study, the TD group identified the emotion "fear" least correctly but identified the emotion "sadness" most frequently. However, the difference in emotion recognition of sadness between the groups did not reach significance. One possible reason for this difference is that the Griffith et al. study [40] used images of children and adults expressing emotions at varying levels of intensity. By contrast, our study used a single image per emotion of a child displaying a single (high) level of intensity. Additionally, there were no differences between the groups in the recognition of the emotion "happiness" in our study. Both groups were able to recognize this emotion equally well and could therefore be used as a baseline or control variable.

Overall, the TD group reported a specific example of a situation in which the emotion was experienced more often than the ASD group did. This descriptive finding may support findings by Huggins et al. [45] that individuals with ASD have difficulty recognizing and understanding their own emotions. However, only the difference in naming a specific situation for the emotion "sadness" was significant. Thus, it appears that children with ASD generally have difficulties with the emotion "sadness", both in recognizing it and in naming a specific example. Although it is well-known that people with ASD have difficulty recognizing emotions, this may not be the only reason for the observed differences between the TD and ASD groups. This task may require more complex cognitive processing than pure emotion identification because asking for an example requires a precise understanding or reconstruction of a (possible) context. For example, in a social film experiment, Hochhauser et al. [87] were able to show that individuals with ASD were less able to consider different protagonists quickly and flexibly than individuals with TD, and that this was connected to the perspective-taking difficulties of the participants with ASD. The group difference in the present task could indicate that the item 'give an example' requires more complex processes, such as perspective taking, visual attention, and language production, and thus indicates more difficulty than pure emotion recognition.

To assign children to either the ASD or TD group via the emotion recognition task, it seems sufficient to use only emotion recognition of fear and sadness. If the children recognized the emotion "fear" correctly, they were assigned to the ASD group. If the children do not correctly recognize the emotion "fear", they are checked to see if they correctly recognize the emotion "sadness". If they do not, they are once more assigned to the ASD group. If they recognize the emotion "sadness" correctly, they are assigned to the TD group. With an accuracy of 81.25%, a sensitivity of 91.67% and a specificity of 70.83%, the diagnostic accuracy is quite good.

Visual preference task

Many studies have shown that children with ASD, often under six years of age, have a significantly greater preference for non-social stimuli than for social stimuli [54, 55]. However, this result was not observed in our study of 6- to 11-year-olds. Here, the relative duration of gaze fixation was significantly greater for social images than for non-social images in both groups. However, a study by Matyjek et al. [62] showed that in adulthood, people with ASD no longer preferred non-social stimuli over social stimuli. Instead, the difference between the ASD and TD groups is that people with ASD do not discriminate between the presentations, whereas a difference occurs in the TD group. Our results support this interpretation, as we found a significant difference for the video medium in the TD group, i.e., the relative duration of gaze fixation for the social video was significantly greater than that for the non-social video. In contrast, no difference was found in the ASD group. The different visual preference results observed in toddlers, children, and adults, both with and without ASD, suggest potential changes in diagnostic patterns over time. However, due to the lack of longitudinal data, it is not possible to draw any conclusions about how the significance of symptoms is represented over the course of a child's development.

Additionally, no differences were found in this study in terms of the frequency of gaze changes. However, the change in gaze in the medium video based on the decision tree seems to be a predictor – together with the percentage of time spent watching the social video – for the classification of the groups. If the children had a relative duration of gaze fixation greater than 55% on the social video, they were assigned to the TD group. If the relative duration of gaze fixation was less than 55% and they changed their gaze less than 16.5% on the video, they were also assigned to the TD group. This was also the case if their gaze shifts were above 32.5%. If their gaze shifts were between 16.5% and 32.5%, they were assigned to the ASD group. With an accuracy of 81.25%, a sensitivity of 70.83%, and a specificity of 91.67%, the diagnostic accuracy is promising.

Task validity for clinical use

Overall, the prediction accuracy of the models of the two tasks is 81.25%. In the emotion recognition task, 17 out of 24 TD children and 22 out of 24 children with ASD were correctly predicted. In the visual preference task, the results were reversed. This suggests that both tasks can be used for digital screening, and it is appropriate to combine them, as they are complementary. We conclude that digital screening can be implemented by existing

digital technologies and that selected emotion recognition and visual preference tasks can discriminate between children with and without ASD.

Limitations and implications

However, it is important to note that the predicted values apply only to this sample and should not be generalized. Another limitation is the sample size of only 24 children per group (ASD and TD), although this is a typical sample size for clinical or ASD studies and is large enough for analysis. However, this small sample size increases the risk of reduced statistical power and model instability. Similarly, the number of predictor variables increases the risk of overfitting the model. Therefore, the results should be interpreted with caution. Notably, not all diagnosed children in the ASD group met the threshold for suspected ASD on the parent-completed FSK (the FSK score was negatively correlated with the duration of therapy). However, this was accounted for in the analyses and had no significant effect. Thus, the two tasks appear to be independent of any therapy received to date, which is a strength in itself. However, this is surprising in regard to the emotion recognition task, given that emotion recognition is often addressed in therapy. Currently, there is no information available regarding the therapy that has been provided to the children. It is possible that emotion recognition has not yet been addressed in therapy. Overall, the task of emotion recognition has two methodological limitations. Firstly, the images only depict female individuals, even though the participants were male. This restricts the generalizability of the results, given that Hoffner [88] reported that people tend to identify more with people of the same gender and find them more attractive. Secondly, the single representation of each emotion restricts variability and may not capture the full range of expressions associated with it. This could reduce the robustness of the task.

The composition of the sample is also a limitation. The sample consists only of boys, which means that the results cannot be extrapolated to girls or other genders. This is also a typical sample for an ASD study, as there is an assumption that the phenotype of female autism is qualitatively different from that of male autism [66]. The study by Burrows et al. [89] indicated that girls demonstrated milder symptoms than boys. In addition, children with ASD and intellectual impairment were not included in this study, as children with ASD and intellectual impairment are more likely to be diagnosed than are children with ASD without intellectual impairment [13]. Therefore, digital screening is particularly needed for the group of children suspected of having ASD without intellectual impairment. It should be emphasized that the level of accuracy is high in both tasks, despite the presence of additional diagnoses in both groups. The results may be impacted by comorbidities. It would be interesting to investigate whether accuracy improves when children in the TD group do not have a diagnosis and children in the ASD group only have an ASD diagnosis. It is possible that the contradictory results of combining the two tasks are due to the additional diagnoses, such as ADHD. This should be verified.

A technical limitation of the visual preference task is that – because the tablet's camera was located on the left side –, eye tracking worked better on the left side of the screen than on the right (see [60]). Therefore, a tablet with a camera in the center should be used in further investigations and will be implemented in future tests of the IDEAS project.

Despite the above limitations, our study has several strengths. In our study, we reported the sensitivity and specificity of typical discrimination tasks described in the ASD literature. The results are based on small yet adequate sample sizes, which are typical of ASD research. For the analyses, we used an advanced statistical model class of decision trees to estimate sensitivity and specificity, which represents the state of the art in statistical analysis and controls for the influence of therapy duration.

To replicate these study results and verify the accuracy of the prediction, a new sample should be collected in the future. The sample size should also be increased in future studies. As the long-term goal is to contribute to the early identification of ASD, this study should be repeated with younger children. In Germany, ASD is diagnosed at an average age of 6;6 years [13]. When testing younger children, therefore, there may only be a suspicion, rather than a diagnosis. In this case, it would be necessary to check whether children identified through the tests were later diagnosed with ASD. In terms of potential gender differences, future studies should include girls with and without ASD, boys with and without ASD, and mixed-gender groups with and without ASD. It is important to conduct the study with both girls with and without ASD. For example, a study by Burrows et al. [89] showed that the gender ratio was balanced within the group classified as being at high risk of ASD. Burrows et al. [89] conclude that girls may be underdiagnosed because their symptoms are more subtle and cannot be adequately captured by current diagnostic tools. Therefore, it would be worthwhile to investigate whether the tasks used in this study can also identify girls with ASD. Moreover, the target group of the ASD group consists of children with ASD without intellectual impairment who can communicate verbally. It would be interesting to conduct a similar study with children with ASD with intellectual disability who communicate via augmentative and alternative communication (AAC) to investigate whether a digital screening based on the visual preference task might also

be appropriate for children who use AAC, as no verbal speech is needed, only gaze.

Our study shows promising results that may facilitate the identification of children with ASD without intellectual impairment in the future. New task formats may be considered for this purpose. As the emotion recognition task is currently administered verbally, future studies should test whether the task works at least as well when children are asked to select the emotion emoji instead of naming the emotions. Mimicry tasks should also be tested in the future. Studies have shown that mimicry is lower in people with ASD and that the differences between groups in terms of mimicry can also occur when individuals interact with avatars [90]. In this context, Dotzer et al. [91] investigated whether facial expression recognition (FER) reliably detects smile events and whether facial expressions can thus be digitally and automatically recorded and scored. The result was that the FER reliably recognized smile events and corresponded to a human evaluation [91]. This could therefore be transferred to the emotion of happiness and should be verified for other basic emotions.

Conclusion

Ultimately, digital automated screening might promote (in future) earlier detection of ASD. However, it is not intended to replace diagnostics but can support clinicians by objectifying a step of the decision-making process, reducing the burden of clinical practice, and providing a resource (cf [21]). Relief could be provided by using objective digital screening to remove children who are not suspected of having ASD from the waiting list for the diagnosis of ASD, thereby reducing the number of children on the waiting list. Digital screening can therefore be a resource and a relief for clinicians and families with suspected cases of ASD.

Abbreviations

AAC	Augmentative and alternative communication
AD(H)D	Attention-deficit (hyperactivity) disorder
ASD	Autism spectrum disorder
EAST	Early autism screening tool
FER	Facial expression recognition
FSK	German version of the Social Communication Questionnaire
IDEAS	Identification of Autism Spectrum Disorder using speech and facial expression recognition
SACS	Social Attention and Communication Surveillance
TD	Typically developing
WIN4ASD	Web Italian Network for Autism Spectrum Disorder

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12888-025-07725-z.

Supplementary Material 1

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Author contributions

LP developed the concept and collected the data. MB developed and provided the software. LP and MB prepared the data. LP performed all analyses and interpretations. OK assisted in selecting the analysis methods. LP drafted the manuscript. All authors reviewed and approved the final version of the manuscript.

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Data availability

The data will be shared upon reasonable request to the corresponding author with the permission of the entire consortium (Fraunhofer Institute for Digital Media Technology; KIZMO GmbH; SpeechCare GmbH; University of Leipzig Medical Center; TU Dortmund University).

Declarations

Ethical approval

The study involving human participants was reviewed and approved by the Joint Ethics Committee of Departments 9 and 11–17 at TU Dortmund University (GEKTUDO_2022_45). The research was conducted in accordance with the Declaration of Helsinki.

Consent to participate

After written information about the study, written informed consent to participate in this study was provided by the participants' legal guardian/next of kin. The children gave their verbal consent during the test appointment.

Consent for publication

The participating families have given their written consent for publication.

Competing interests

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as potential conflicts of interest. Author 3 declares that KIZMO GmbH is interested in commercializing the software developed by the company.

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