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Child–Computer Interaction: From a systematic review towards an integrated understanding of interaction design methods for children

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ABSTRACT

Child–Computer Interaction (CCI) is a steadily growing field that focuses on children as a prominent and emergent user group. For more than twenty years, the Interaction Design for Children (IDC) community has developed, extended, and advanced research and design methods for children's involvement in designing and evaluating interactive technologies. However, as the CCI field evolves, the need arises for an integrated understanding of interaction design methods currently applied. To that end, we analyzed 272 full papers across a selection of journals and conference venues from 2005 to 2020. Our review contributes to the literature on this topic by (1) examining a holistic child population, including developmentally diverse children and children from 0 to 18 years old, (2) illustrating the interplay of children's and adults' roles across different methods, and (3) identifying patterns of triangulation in the methods applied while taking recent ethical debates about children's involvement in design into account. While we found that most studies were conducted in natural settings, we observed a preference for evaluating interactive artifacts at a single point in time. Method triangulation was applied in two-thirds of the papers, with a preference for qualitative methods. Researchers used triangulation predominantly with respect to mainstream methods that were not specifically developed for child participants, such as user observation combined with semi-structured interviews or activity logging. However, the CCI field employs a wide variety of creative design methods which engage children more actively in the design process by having them take on roles such as informant and design partner. In turn, we see that more passive children's roles, e.g., user or tester, are more often linked to an expert mindset by the adult. Adults take on a wider spectrum of roles in the design process when addressing specific developmental groups, such as children with autism spectrum disorder. We conclude with a critical discussion about the constraints involved in conducting CCI research and discuss implications that can inform future methodological advances in the field and underlying challenges.

Contents

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1. Introduction

Children have become regular users of interactive technologies in the last two decades. For instance, a recent survey found that 42% of the children in the United Kingdom between the age of five to seven own a tablet (Burns & Gottschalk, 2019). As children became increasingly relevant as users and study participants for interaction designers and researchers in the 1990s (Druin, 1999), the field of CCI[1] began to grow steadily. A community with multidisciplinary influences emerged (Hourcade, 2015), which emphasizes designing interactive technology for children that supports their development as a key design goal, based on contributions from diverse fields, including developmental psychology, learning science, interaction design, and computer science (Hourcade, 2015). Therefore, researchers in this field stress the importance of better understanding of how research methods can be adapted to address emerging developments (Jensen & Skov, 2005).

Research in CCI focuses on questions concerning the design of interactive technologies for children and the effects that technologies can have on children and society (Hourcade, 2015). An important component of this quest has been the endeavor to develop new methods to design and evaluate how children interact with novel technologies. This quest parallels the evolution of the field, since for CCI to stay relevant, its methods should evolve as the world around children changes (Markopoulos, Read, MacFarlane, & Hoysniemi, 2008). These methods are often adaptations of methods originally developed for working with the adult population, although several methodological advances have been proposed to specifically address children's needs and capabilities.

CCI researchers have recognized the need to take stock of advances in the field and have produced a number of contributions that review and synthesize earlier research results. For example, Markopoulos et al. (2008) present an overview of evaluation methodologies for children's interactive products in a textbook format; however since its publication, there have been substantial methodological developments, which are reviewed below. Fails, Guha, and Druin (2012) synthesized methodological advice for designers of children's technology, focusing on motivation and practical ideas for including children in the design process. Hourcade's (2015) textbook provides an instructional overview of the CCI field that also includes methods for designing and evaluating interactive technologies for children, although it was not intended as a systematic, comprehensive survey of the related literature. We add to these resources by providing a systematic and up to date literature survey of CCI methodology. Our survey follows a number of literature surveys in the CCI field with different areas of focus. For example, earlier reviews focused on aspects such as the agency of children with autism, children in technology design (Spiel, Frauenberger, Keyes, & Fitzpatrick, 2019), HCI[2] games for neurodivergent players (Spiel & Gerling, 2021), engaging and educating children in technology-making activities (Norouzi, Kinnula, & Iivari, 2019; Ventä-Olkkonen, Hartikainen, Norouzi, Iivari, & Kinnula, 2019), as well as values and ethical aspects (Kawas, et al., 2020; Van Mechelen, Baykal, Dindler, & Eriksson, 2020). Our aim is to provide an overview of interaction design methods that can serve as a resource for designers and researchers in this field. More recently, a review of CCI methods by Tsvyatkova and Storni (2019) shared some of the aims of this paper, but focused more narrowly on methodology papers in order to provide guidance for selecting and adapting methods, techniques, and tools for working with neurotypical children. There is a need to extend the methodological discussion to a broad group of children, reflecting the interest this community has paid over the years on their inclusion (Börjesson, Barendregt, Eriksson, & Torgersson, 2015).

Recent methodological reviews in the field of human–computer interaction for the adult population have stressed the importance of investigating triangulation patterns in method application to better inform scholars and practitioners of the advantages of combining quantitative and qualitative methods, for instance (Pettersson, Lachner, Frison, Riener, & Butz, 2018). To the best of our knowledge, triangulation patterns have not been systematically explored by other reviews in the CCI field. This review will therefore pay particular attention to the triangulation of methods.

In addition, we investigate the roles adults take in interaction design methods that include roles for children as well in order to uncover patterns and differences in method application. Children's roles are enduring topics in CCI, and adults' roles are particularly significant for work with children as well. This is the first paper to provide such an integrated overview of the state of the art of interaction design methods for children. We meet this challenge by analyzing 272 full papers reporting empirical studies that have been published over the last 15 years. Our work is guided by the following research questions:

[1] Child–Computer Interaction (CCI).

[2] Human–Computer Interaction (HCI).

- How did interaction design methods and triangulation patterns with children between the ages of 0 and 18 evolve during the period of 2005 to 2020?
- How are interaction design methods applied across groups of developmentally diverse children and in different contexts?
- How do the different roles of children and adults in the research and design process inform the selection of a specific method or vice versa?
- What are current practices regarding ethical conduct in research?

The overarching goal of this review is to provide guidance for future studies in the field and support methodological advancements. Systematic reviews offer a unique opportunity to analyze the literature on a combined set of questions, rather than conducting repeated surveys for individual questions. Addressing a broad set of questions in a single survey can provide a single coherent overview for the research community. Based on earlier work, we identified gaps in the current literature and synthesized the contributions for this systematic review. Our review contributes to the research in this field by (1) examining a holistic child population, including developmentally diverse children and children from 0 to 18 years old, (2) illustrating the interplay of children's and adults' roles with different methods, and (3) identifying triangulation patterns in method application while taking recent ethical debates regarding children's involvement in design into account. We begin the systematic review with an outline of similar reviews in the field to further motivate our research interest. We then provide the details of our review methodology and its findings. This is followed by a discussion of the implications of our results.

2. Related work

CCI has an established tradition of and appreciation for literature reviews to analyze current trends and guide future developments of the field. To date, literature reviews on a variety of different topics have been published,such as designing for neurodivergent populations (Spiel et al., 2019; Spiel & Gerling, 2021) and engaging children in technology making activities (e.g., Norouzi et al., 2019; Ventä-Olkkonen et al., 2019). In this section, we provide an overview of recent literature reviews in CCI, with a particular focus on methodological reviews, that is, literature reviews that analyze the methods applied in the field and related aspects. The reviews described here were selected in a systematic approach. While setting the scope and framing the context of the current review, we searched for similar reviews in the ACM[3] database published in the period from 2005 to 2020. In our search, we used the terms *review*, *survey* or *meta-analysis* together with the terms *child*, *kid*, *teen*, *youth*, *young*, *adolescent*, or *minor*. The search of the ACM full-text collection resulted in 119 records. After screening all records, we identified a variety of review papers addressing current trends in method application in the CCI domain from different angles (Börjesson et al., 2015; Jensen & Skov, 2005; Tsvyatkova & Storni, 2019; Yarosh, Radu, Hunter, & Rosenbaum, 2011).

Jensen and Skov's (2005) review focused on research methodologies used in papers reported in IDC[4] proceedings and selected journals between 1996 and 2004. They classified 105 papers on children's technology design into a two-dimensional matrix on research methods (e.g., case studies, field studies, lab experiments) and research purposes (understand, engineer, re-engineer, evaluate and describe). In contrast, we decided to apply a classification system that describes the underlying methodology in more detail (e.g., user observation, semi-structured interviews, activity logging), similar to the review by Börjesson et al. (2015). Börjesson et al. (2015) developed their framework in line with new trends in the participatory design field by incorporating methods such as creative sessions and prototyping, which we did not find in any of the categories defined by Jensen and Skov (2005). Additionally, Jensen and Skov (2005) found that much research has been conducted in natural settings, with a strong focus on field studies. Our review examines how this trend has evolved in the last fifteen years based on an updated classification framework of methods.

A review by Yarosh et al. (2011) examined the values held by the CCI community. They conducted a content analysis of values expressed in full papers published at the ACM IDC conference between 2002 and 2010. They discussed several types of contributions made by IDC papers and examined, inter alia, the role of the child in technology design based on Druin's framework (Druin, 2002). Druin (2002) defines four roles that children can play in the research process: user, tester, informant, and design partner. Our review adopts a similar understanding of children's roles by analyzing two of the underlying dimensions upon which these role definitions are based: *the relationship to adults* (which we further refer to as feedback from children, which spans from passive to active), and the *goals for inquiry* (which we further refer to as research vs. design-led) (see Fig. 1, from Druin (2002), pag.5).

We extend such research on the role of the child by also examining the role of adults in the design process. In current methodological approaches in the CCI field, such as participatory design, children are given stronger voices in the research and design process. For instance, there has been a shift away from children taking on roles such as participants in user studies, which are typically applied in a user-centered design approach, to more enhanced roles like peer codesigner (Nesset & Large, 2004). However, the importance of adult involvement throughout the research and design process should not be underestimated. The inclusion of caregivers, teachers, or other experts in the field remains critical, especially for younger user groups and developmentally diverse children (Börjesson et al., 2015). Therefore, we stress the importance of investigating the interplay between these different roles taken on by children and adults in the design and evaluation process, as this could potentially inform the selection of appropriate methods.

In addition to identifying many positive aspects in the surveyed papers, Yarosh et al. (2011) also shared a number of suggestions for improving future research. They concluded that the majority of IDC papers target children between the ages of 6 and 12. The need to work with other age groups seems apparent due to the need to design and evaluate technologies in an age-appropriate way. Thus, our review considers a broad age range, from infants aged 0 years to late adolescents aged 18 years. Moreover, Yarosh et al. (2011) further expressed the need for longer-term evaluations, as stated here: "the difficulty of deploying and evaluating a system over a longer period of time cannot be underestimated, however, neither can the importance of doing so" (p. 143) (Yarosh et al., 2011). They further state that short-term evaluations can merely address usability aspects and engagement, rather than long-term effects such as learning. This review will shed light on the *temporal stage of system usage* (anticipated, momentary, episodic, retrospective, cumulative experience) as reported by Roto, Law, Vermeeren, and Hoonhout (2011), *cross-sectional vs. longitudinal evaluation* (at one moment in time or several moments) and the study's goals (Druin, 2002), taking up Sanders's (2008) distinction between a research-led vs.

[3] Association for Computing Machinery (ACM).

[4] Interaction Design and Children (IDC).

Role of child	Relationship to adults				Relationship to tech			Goals for inquiry		
	indirect	feedback	dialogue	elaborate	ideas	prototype	product	theory	impact	usability
User	x						x	x	x	
Tester	x	x				x		x	x	x
Informant	x	x	x		x	x	x		x	x
Design Partner	x	x	x	x	x	x	x			x

Fig. 1. The four roles children may take on in the design of technologies (Druin, 2002).

a design-led approach in her evolving maps of design practice and research.

In 2015, Börjesson et al. (2015) published a systematic literature review of methods for developmentally diverse children. They stated, "compared to other groups of developmentally diverse children, children with high-functioning autism between 8 and 12 years old are the ones that are most often actively involved in the design process. The other groups of children are often taking a more passive role, like being observed, both in the requirements, design, and evaluation phase" (p. 136) (Börjesson et al., 2015). Our review focuses on the whole child population from infants to late-stage adolescents and includes developmentally diverse children. With this approach, we can cross-validate methods rather than treat them as distinctive from one child population to the other. Our goal is to inform the development of more accessible and inclusive research methodologies. Therefore, our analysis of methods is based not on children's biological age but on the type of feedback children provide across the various methods underlying Druin's definition of children's roles (Druin, 2002). The type of feedback children are asked to provide guides our evaluation of the appropriateness of a method in a given context.

Tsvyatkova and Storni (2019) conducted a review of methods, techniques, and tools in CCI developed/adapted to support children's involvement in technology development based on 36 methodological papers published between 1996 and 2015. The authors classify methods and techniques in CCI based on the framework by Sanders (2008), which maps them along a continuum from an expert to a participatory mindset. Sanders (2008) uses this continuum to classify design and research approaches, with their underlying methods, on her evolving map. This idea of a participatory continuum harkens back to earlier research in the CCI community, such as the IBF Participatory Continuum Model developed by Read et al. (2002). The letters IBF stand for the three different design contributions a domain expert can make. It begins with the lowest contribution, termed *informant design*, and proceeds to *balanced design* and finally *facilitated design,* the highest level of contribution. The review by Tsvyatkova and Storni (2019) applies the participatory continuum to recent CCI methods, techniques, and tools. However, this review did not include the full framework presented by Sanders, which consists of two continua, from an expert to a participatory mindset and from a research- to design-led selection of methods. As stated before, we believe that children's degree of involvement across different methodologies can provide us with guidance for choosing the right method in a given context. Therefore, we adopted the original framework (Sanders, 2008), introducing the type of children's feedback on the first continuum (similar to the original continuum from an expert to a participatory mindset) and maintaining the second continuum of design vs. research-led approaches. The results obtained by applying this framework have a different base than in Tsvyatkova and Storni's (2019) work because we (1) utilize a different classification scheme for our methods and (2) draw on a selection of empirical studies and case studies rather than a selection of methodological papers. We want to stress the importance of tracing back how the methods we propose are implemented in the field to shape a more realistic picture and state of the art, providing us with the possibility to improve and iterate on our methods.

Keeping the above reviews in mind, one important aspect has not been addressed to our knowledge in the CCI community so far, namely the triangulation of methods. Within the broader human–computer interaction (HCI) research community, a recent review addressed the importance of method triangulation for the adult population (Pettersson et al., 2018). The early roots of triangulation can be found in the different epistemological standpoints taken in social, behavioral, and human science. The interplay of qualitative and quantitative methods can help researchers addressing the same problem from different angles to derive a fuller understanding of it. The application of multiple methods within the same study is known as *concurrent* triangulation and can lead to a more reliable and less biased investigation (Creswell, 2009). A *sequential* triangulation of methods, by first using quantitative methods and later qualitative methods, can lead to a fuller and more holistic picture, highlighting different dimensions of the same phenomenon (Creswell, 2009).

In recent years, we have observed a growing interest in ethics within the CCI community, which are addressed in a recent systematic review by Van Mechelen et al. (2020). In their paper, they explore how and to what extent ethics has been dealt with over the last 18 years. They demonstrate that while ethics is frequently mentioned, the literature remains underdeveloped in a number of areas, including definitions and theoretical foundations, the reporting of formal ethical approval procedures, and the extent to which design and participation ethics has been dealt with (Van Mechelen et al., 2020). As our review seeks to deliver an integrated understanding of interaction design methods based on empirical papers, we were especially interested in how and to what extent formal ethical approval is reported in the CCI literature, in order to provide a realistic picture of the state of affairs.

3. Method

To develop an integrated understanding of interaction design methods focusing on a diverse population of children, triangulation patterns, and the roles of children and adults, we conducted a systematic literature review. This systematic review follows the PRISMA statement, which stands for *Preferred Reporting Items for Systematic Reviews and Meta-Analyses* (Moher, Liberati, Tetzlaff, & Altmann, 2009). We present our detailed methodological approach in this review in 5 main steps.

3.1. Step 1: Identification of potentially relevant publications

Search terms. Based on our research questions and inspired by the review by Börjesson et al. (2015), we performed a search query in papers' abstract for the terms *"design method" OR "design process" OR "design approach"* etc. ***AND*** in the title for *child* OR kid* OR adolescent*,* etc. (see Table 1). The characters (" ") reflect a search for the exact match of that phrase, whereas (*) specifies a number of unknown characters. For example, when using the expression child*, the search engine results will also contain words such as children or childhood. We limited our second search term

Table 1
The search query with search terms 1 in title and search terms 2 in abstract.

Search term 1 (Title)	Boolean operator	Search term 2 (Abstract)
Child(ren)		Design method(s)
Kid(s)		Design process
Adolescent(s)		Design approach
Minor(s)		Design technique
Youth		Interaction design
Teen		User-centered design
Teenager		User experience
Young	OR	Human-centered design
Student		Child–computer interaction
Pupil		Human–computer interaction
		User-system interaction
		Inclusive design
		Universal design

Note: Terms were searched in both their British and American English forms.

to the abstract because we found that searching for the terms in the complete text returned too many false positives, which we would then have to remove later on based on our exclusion criteria. The same was the case for our target group (first search term). After several iterations, we found that searching for the term in the complete text or abstract resulted in too many false positives; therefore, we decided to search for it in the title only.

Database selection. We selected journal papers from the SCOPUS database and ACM Digital Library. A structured database search within SCOPUS identified 6963 potentially relevant papers from January 2005 to July 2020 (when the database search was conducted). We started our systematic review with papers from 2005 onwards, as the earliest literature review we identified in our search for related workcovers studies until 2004 (Jensen & Skov, 2005). After filtering for document type *"article"*, source type *"journal"* and publication stage *"final"*, a total of 2844 references remained. Within the ACM library, we identified a total of 3750 papers. After filtering for proceedings and research articles (to exclude short papers and extended abstracts), 1528 papers were left.

Selection of Journals and Conferences. We included 7 top-level journals (based on the selection by Jensen and Skov (2005)) plus the International Journal of Child–Computer Interaction. In line with arguments by Jensen and Skov (2005), we find that the pool of included journal papers provides a solid base for our review given the number of papers and the journals' high-quality peer review process. We further narrowed the scope to two suitable target conferences (IDC, CHI) based on their relevance for our study aim. These two venues seemed to be the dominant venues for our target audience because they returned the most hits for our search query. We excluded the International Conference on Human-Computer Interaction (HCII) proceedings, for example, because they are only reviewed based on abstracts, and we wanted to focus on peer-reviewed venues. We also excluded education technology conferences such as the International Conference on Education Technology and Computers (ICETC) proceedings, because these communities do not focus specifically on developing methodologies for interaction design. In addition, the choice of scope was made in order to retain a manageable corpus of papers.

The PRISMA flowchart (Fig. 2) presents the overall distribution of publications per journal and conference venue. We counted a total of 829 papers after checking for duplicates. Additional false positives (e.g., no full paper) were excluded at later stages.

Journals:

- Transactions on Human-Computer Interaction, (ToCHI) ACM
- International Journal of Human-Computer Studies, (IJHCS) Elsevier
- International Journal of Human-Computer Interaction, (IJHCI) LEA
- Behaviour and Information Technology, (BIT) Taylor & Francis
- Interacting with Computers (IwC), Elsevier
- Personal and Ubiquitous Computing, (PUC), Springer-Verlag
- International Journal of Child Computer Interaction (IJCCI), Elsevier

Conference proceedings:

- Interaction Design and Children Conference (IDC), ACM
- Conference on Human Factors in Computing Systems (CHI), ACM

3.2. Step 2: Definition of scope and procedure

We conducted two rounds of exclusion. The first round aimed to quickly exclude papers based on formal criteria, whereas the second round narrowed the scope based on content.

Exclusion criteria 1st round. We double-checked for the presence of false positives in our selection based on the paper format. We therefore excluded papers **(1)** that were not full papers. In the Interaction Design and Children Conference proceedings, the distinction between short and full papers is sometimes blurred. According to the paper submission guidelines of the 2019 Interaction Design and Children Conference, papers of 8 pages or more were classified as full papers. **(2)** We further excluded papers that did not include an empirical study, or did not include a clear description of the evaluation process or the study results. Case studies, even with a single child, were included as long as user data were reported in a clear way. Studies based on the author's self-reflection or introspection, without involving children, were excluded. **(3)** Papers were excluded that did not report research with children directly (e.g. research with adults about products for children was excluded). **(4)** Papers reporting studies with participants more than 18 years old were excluded, except if only part of the sample was above age 18 (e.g. 16–24), in which case we included the paper.

Exclusion criteria 2nd round. We excluded papers **(1)** that did not report a new study and solely referred to former ones, **(2)** that relied solely on perceptions or psychological factors, with no tangible or interactive artifact involved. We included, however, early studies that did not evaluate a specific system/technology/tool but described a system/technology/tool authors intended to design in the future.

Procedure. Studies were selected independently by the first two authors based on a screening of titles and abstracts.

Miles, Hubermann, and Saldana (1994) (p. 11) emphasize the importance of conclusions being verified, whether by reference back to field notes, achieving "intersubjective consensus" through discussion with colleagues, or replicating findings in another dataset. Thus, the selected papers were cross-checked during two exclusion rounds, and discrepancies were resolved by including the third author to reach a consensus about study inclusion.

3.3. Step 3: Identification of relevant publications

In Fig. 2, we outlined how the exclusion process of the selected articles was performed according to the PRISMA statement.

3.4. Step 4: Categorization of relevant publications

Coding scheme. Our coding scheme was developed in an iterative approach to ensure that the categories were understandable and easy to use. We tested the coding scheme with a group of eight HCI researchers to gain external expert feedback and ensure that coding would not assume specialized skills or prior knowledge. Our final coding scheme used for the analysis consisted of *20 codes*, classified into several **code groups**.

1. **General study setup** codes included the *type of paper* (conference, journal), *type of study* (natural, artificial,

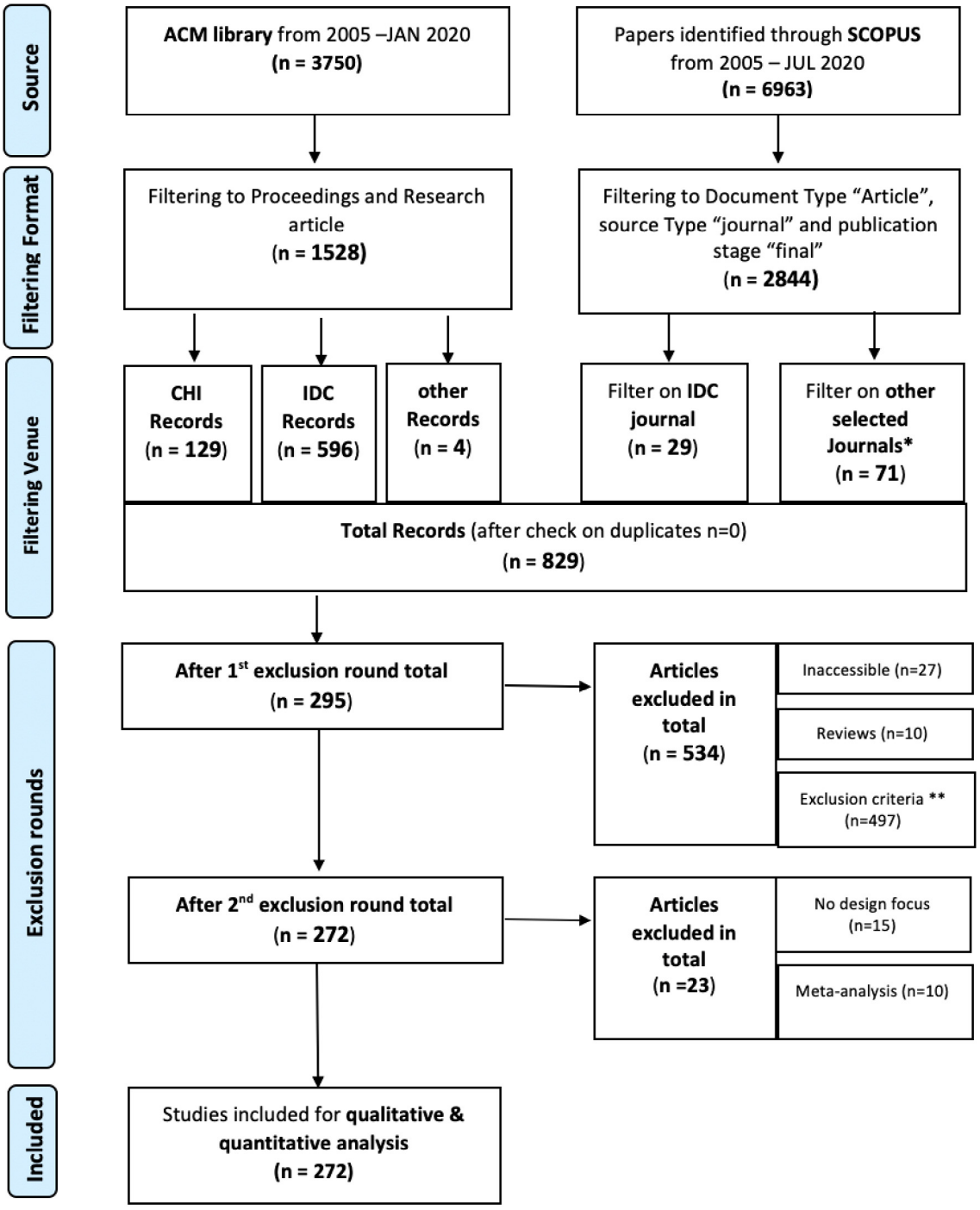

Fig. 2. Flow chart of our systematic review adapted from the PRISMA statement (Moher et al., 2009).

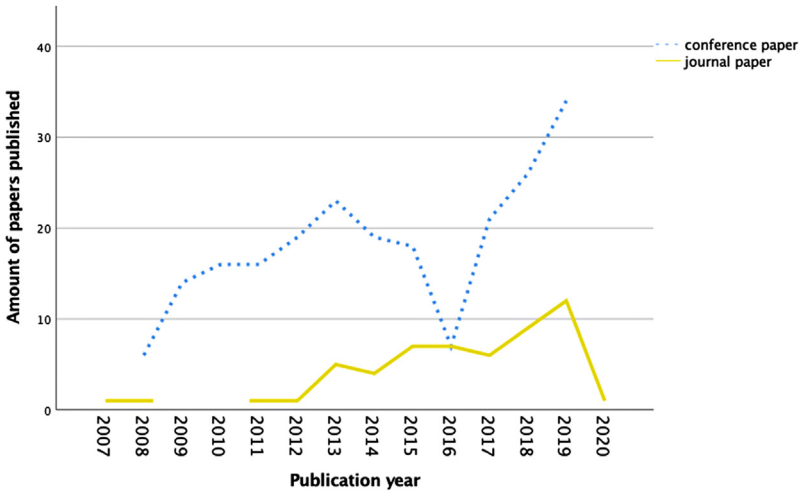

Fig. 3. Publication trend for all papers included in the review, from 2007 to 2020 (conference venues until January 2020 and journal papers until July 2020).

environment-independent, combination), *study location*, and *product evaluated*.

2. **Methodology** codes included the *temporal stage of system use* (anticipated, momentary, episodic, retrospective, cumulative experience, and any combination), *longitudinal vs. cross-sectional evaluation*, classification of the *special developmental group, method triangulation, data triangulation (qualitative vs. quantitative), method type* (e.g., user observation, semi-structured interviews, standardized questionnaires, etc.), the *specific methods used* (note that we did not distinguish between methods, techniques and tools, as most of the papers included in this review did not do so) (Börjesson et al., 2015).
3. **Information about the sample** was also coded, including the *age of the children* (including the upper and lower age bounds) and the *number of participants*. Those codes were applied for all methods separately in cases in which multiple methods were reported in a single paper.
4. **Children's roles** were classified based on Druin's model (Druin, 2002), focusing on the relationship to adults *(indirect, feedback, dialog, elaborate*), which we hereafter refer to as *feedback from children* on a continuum from *passive to active*, and the goals for inquiry (*theory, impact, usability*), which we hereafter refer to on a continuum from research to design-led (see Fig. 1). We also coded the form of involvement of adults in the research and design process by using Börjesson et al.'s (2015) classification to distinguish *adults' roles* (user, proxy, expert, facilitator, support).
5. **Ethical guidelines** focus on *informed consent* and *ethical approval* as mentioned in the papers.

3.5. Step 5: Analysis of relevant publications

Procedure. All included papers were coded by the first author. 10% of the papers were double-coded by the first and second authors. The interrater reliability was found to be Kappa = 0.59 ($p < .05$). According to Landis and Koch (1977), this is a moderate level of agreement. However, we found it more important to achieve group consensus by reconciling discrepancies between the coders than to achieve a high inter-rater reliability score (p.93) (Blandford, Furniss, & Makri, 2016). Therefore, the coders extensively discussed the 10% of double-coded papers on a weekly basis. For the remaining 90%, the first author marked the papers about which she was uncertain and asked the second author for input during their weekly meeting. In cases of disagreement, the third author was brought in, and corresponding adjustments in the coding scheme were made.

Quantitative Analysis. The quantitative analysis of the relevant coded data set was conducted in SPSS v.25.

4. Results

We present the results beginning by charting the temporal trends and perspectives, followed by a description of the child population addressed in terms of age and developmental group. We then elaborate on the context in more detail, including research location, type of study, type of product and longitudinal vs. cross-sectional studies. Subsequently, we examine the type of method and triangulation patterns. We summarize our methodological findings in a graphical overview of interaction design methods for children based on the type of feedback from children and the degree to which the reported studies are design vs. research-led. We conclude with a brief analysis concerning ethics in research with children.

4.1. Temporal perspective and trends

Our review shows an increase of both conference and journal papers between 2007 and 2020 (see Fig. 3). Based on our exclusion criteria (see Section 3.4), we did not identify any relevant papers between 2005 and 2006. Furthermore, we only included conference papers archived in the searched databases by July 2020, when our search was executed; therefore, we see a sharp drop in Fig. 3. Conference papers seem to be the more popular venue for publications in the field of child–computer interaction. One reason for this development could be the establishment of the Annual Conference on Interaction Design and Children in the Netherlands in 2002. Interestingly, there has been a sharp rise in conference papers in recent years. Before the first exclusion round, 71.8% of papers in our review were from the proceedings of the Interaction Design and Children Conference. Additionally, we included the ACM Conference on Human Factors in Computing Systems (CHI), which is one of the most prestigious conferences in the broader HCI field (15.5% of all papers included in our review are CHI papers).

4.2. Population of children

The sample size of children participating in the studies ranged from $N = 1$ to $N = 1031$, with an average sample size of 71.03

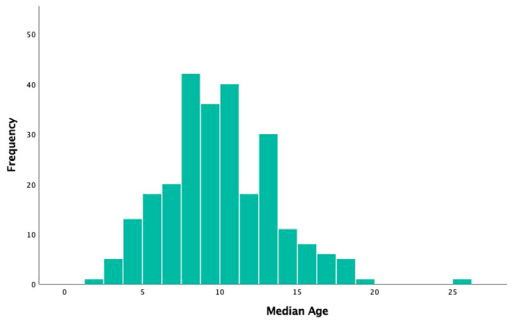

Fig. 4. Age of child participants involved in the reviewed studies, across all interaction design and research methods ($n = 255$).

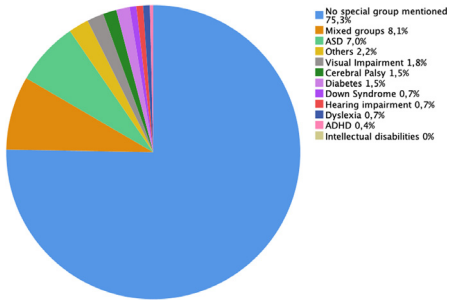

Fig. 5. Distribution of child participants across developmental groups, within reviewed papers ($n = 272$).

($SD = 115.85$). Children from all age groups are represented, with a primary focus on those 7–13 years old (Fig. 4). We calculated the children's median age (based on the lower and upper age range, because only some papers reported the mean age) $M = 9.88$ ($N = 255$ papers, $N = 18{,}610$ child participants overall; $SD = 3.53$). In 17 papers, the participants' age was not stated.

Overall, we can state that children participate across all studies and methods. We found that 75.3% of papers did not mention a specific developmentally diverse group (see Fig. 5). Autism Spectrum Disorder (ASD) is the most frequently represented group within developmentally diverse children, at 7% of papers. Some papers also report studies with mixed groups of normally developing and developmentally diverse children, accounting for 8.1% of total participants across the reviewed papers.

4.3. Context

Research location. The majority of research studies (37.9%) took place in educational institutions (e.g., schools, preschools). 10.7% took place in a laboratory environment, 7.4% at the participants' homes, 5.1% on the premises of health care providers (e.g., clinic, hospital, rehabilitation center), 4% in museums and 3.7% in other places. We also observed that 12.1% of the papers report studies that were conducted in a combination of locations.

Type of study. We distinguished between a natural setting (field studies, case studies, action research), artificial setting (e.g., laboratory), environment-independent/online setting (e.g., survey research, applied research, basic research, normative writing), or a combination of these. Jensen and Skov (2005) applied the same classification in their review, based on earlier work (Wyeth & MacColl, 2010). In our sample of reviewed papers, 55.2% of studies were conducted in a natural setting, 31.3% in an artificial setting, 13.1% in an environment-independent setting, and only 0.4% in a combination of the above. For 13 papers, we could not identify the exact type of study.

Type of product. The most common products studied from 2005 to 2020 were *interactive games* (25.4%), followed by *professional software* (12.1%), *application/mobile phone* (11.8%), *VR/AR* (4.0%), *wearables* (2.6%), *mix of products* (2.6%), *webtools* (2.2%), *websites* (1.1%), *audio/video/TV* (0.7%), *non-digital products* (0.7%) and *other products* (34.7%). We did not further classify this last category due to the heterogeneity in products examined. Examples include a pet robot (Segura, Cramer, Gomes, Nylander, & Paiva, 2012), a multimodal collaborative music environment (Zhou, Percival, Wang, Wang, & Zhao, 2011), an interactive tabletop (Rick, Marshall, & Yuill, 2011) and a digital clay interface (Follmer & Ishii, 2012). We also classified non-use of a product ($n = 16$), for instance developing an educational toolkit (Wyeth & MacColl, 2010), under *other products*. In Fig. 6, it can be seen that products such as VR/AR have arisen more recently in the published papers, whereas interactive games, application/mobile phone and professional software have a longer history.

Examining the distribution of products per developmental group (Fig. 7), *interactive games* are applied for all developmental groups except ADHD. The results presented in Fig. 7 should be interpreted with caution, as the numbers for several developmental groups are quite low. Moreover, *professional software* is also studied in a number of groups, such as ASD, diabetes patients, as well as the typically developing group (no developmentally diverse group mentioned) and mixed groups. An example of *professional software* is computer-generated audio and visual feedback to encourage vocalizations among children with ASD (Hailpern, Karahalios, & Halle, 2009). Apart from typically developing children, ASD seems to be the most frequent target group in the studied products. In Fig. 7, we can also see that a lot of *other products* are used. Moreover, most products were studied in a natural setting: connected service/IOT (100%), wearable (85.7%), VR/AR (70%), interactive games (60.2%). We only found webtools in an artificial setting (80%). Mobile phones/applications and professional software were almost evenly studied in artificial as well as natural settings.

Longitudinal vs. cross-sectional studies. 58.1% of the studies evaluated a product or system at only one moment in time (cross-sectional studies). Of these, 55.9% were conducted in a natural setting. In 41.9% of cases, a product was evaluated several times (longitudinal studies), 44% of such studies were in a natural setting. In terms of development over time, we see a sharp rise in longitudinal studies in recent years, from only two studies reported in 2008 to nine studies reported in 2016 and 20 studies in 2020.

4.4. Method application

We clustered the research and design methods into predefined categories inspired by the reviews by Börjesson et al. (2015) and Pettersson et al. (2018). Börjesson et al. (2015) classified methods and techniques together, arguing that "while there is a fine distinction between methods and techniques we will use these words interchangeably, as most of the papers included in this literature review also do" (p. 80). We decided to merge methods and techniques used in the participatory design field, such as drawing and creating stories with users, under "creative sessions/workshops", similar to Börjesson et al. (2015). In contrast to Börjesson et al. (2015), we decided not to distinguish between pre- and post-interviews but between the exact interview methods used (semi-structured vs. free/open interview), as in Pettersson et al. (2018). We also further specified questionnaires into self-developed questionnaires and standardized questionnaires, as in Pettersson et al. (2018). In contrast to Börjesson et al. (2015), Pettersson et al. (2018), we added cooperative inquiry as a stand-alone method due to the high number of papers

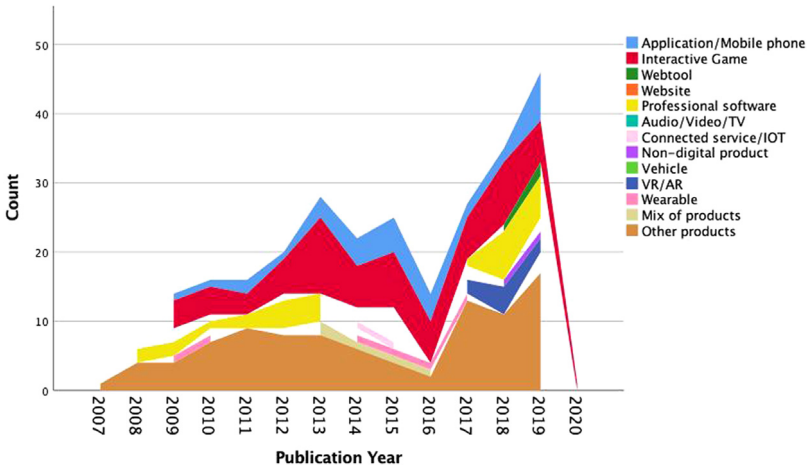

Fig. 6. Distribution of product types over time until July 2020.

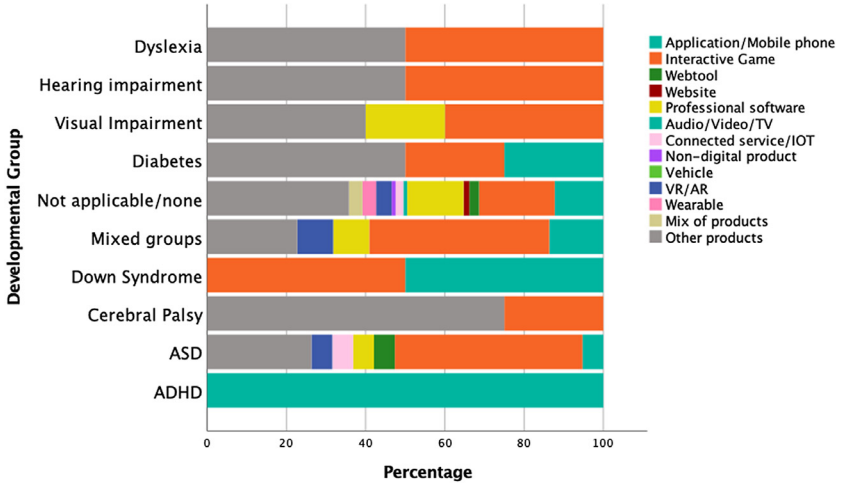

Fig. 7. Type of product by group of children.

mentioning it as a method and the specific methods/techniques underlying it, such as Sticky noting (Kumar, et al., 2018; Woodward et al., 2018). We further decided to classify prototyping as a stand-alone method because we coded it as design-led to a lesser extent compared to the creative sessions (see description of the coding scheme in Section 3.4 point 4). The same was true for brainstorming, which had a stronger research-led focus compared to the creative sessions and was therefore also given a separate method category.

Our coding revealed that the studies reported in the reviewed papers applied various methods, the most popular one being user observation (23.9%). We included in this category field observation and video observation conducted in a laboratory setting. We could identify some observation schemes developed for specific user scenarios, such as outdoor play (Ma, Bekker, Ren, Hu, & Vos, 2018). The second most popular method was semi-structured interviewing (16%), followed by self-developed questionnaires (11.7%) and creative sessions and workshops (11.2%), which encompass a variety of sub-methods and techniques (see Table 2 for all percentages and definitions of the methods).

4.5. Triangulation patterns

The following analysis of triangulation is based on the definitions of methods outlined in Table 2. We observed that two-thirds of the papers use at least two methods (see Table 3). When calculating the triangulation patterns, we took only the main methods into account (those listed in the left column of Table 2).

Looking into concurrent triangulation, that means, the combination of different methods mentioned in the left column of Table 2 within the same study, we found the strongest link between user observation and semi-structured interviews (17.0%), followed by user observation and activity logging (12.6%). Less frequent were combinations of user observation and self-developed questionnaires (7.1%), or semi-structured interviews and self-developed questionnaires (5.4%). In 4.3% of cases, we find combinations of three methods in the same study (typically user observation, semi-structured interviews and self-developed questionnaires). In terms of sequential triangulation, we observed a mixed-method approach, that is, a mix of qualitative and quantitative methods, in 37.9% of papers. Qualitative methods alone accounted for more than half of the selected papers (50.7%), while quantitative methods alone were applied much less frequently (9.2%).

Looking at sequential triangulation in different user groups, we see that qualitative methods are more often applied than quantitative methods for most user groups (see Fig. 8). However, a mixed-method approach is a common choice with children with hearing impairments, Down syndrome and ADHD, for instance. In the visual impairment and Autism Spectrum Disorder (ASD) groups, we observed a preference for qualitative methods. In research with ASD children, user observation (13 out of 19) and

Table 2
Overview of method types and their definitions along with the underlying exact method, technique or tool mentioned by the authors. In the percentage column, we report the frequency of each type of method as a share of all studies. Note: not all reviewed papers mentioned an underlying method, technique or tool and were therefore left blank.

Type of method (with an example reference from our review)	Definition	%	Name of exact method, technique or tool (with an example reference from our review)
User Observation Hiniker, Lee, Sobel, and Choe (2017)	"Observation involves watching and noting what happens, and usually takes place in the situation where the technology of interest is or will be used. The focus may be on work or leisure activities, and how the technology supports, hinders or otherwise shapes them, or on people's interactions with the technology." Blandford et al. (2016)(p. 36)	23.9	Outdoor play observation scheme (OPOS) Ma et al. (2018), Observational System of Motor Skills (OSMOS) Landry, et al. (2013), System for Observation of Children's Social Interactions Raffle, et al. (2010)
Semi-structured interview Scharf, Winkler, Hahn, Wolters, and Herczeg (2012)	"In semi-structured interviews many questions (or at least themes) will be planned ahead of time, but lines of inquiry will be pursued within the interview to follow up on interesting and unexpected avenues that emerge." Blandford et al. (2016)(p. 40).	16	Question-asking protocol Hudson, Lafreniere, Chilana, and Grossman (2018), this-or-that Zaman and Abeele (2010), Rapid desirability testing Fleck, Baraudon, Frey, Lainé, and Hachet (2018)
Self-developed questionnaire Fletcher-Watson, Pain, Hammond, Humphry, and McConachie (2016)	A questionnaire developed by the researchers whose psychometric properties have not yet been tested (unlike for standardized questionnaires, see Boynton and Greenhalgh (2004)).	11.7	
Creative sessions/workshops McRoberts, Yuan, Watson, and Yarosh (2019)	Methods and techniques used in participatory design, such as drawing and creating stories with users Börjesson et al. (2015) and all other creative design activities/workshops not explicitly named as part of the cooperative inquiry method.	11.2	Co-design Hamidi, Saenz, and Baljko (2014), storyboarding Schaper, Santos, and Pares (2018), design critique Frauenberger, Good, Alcorn, and Pain (2013), track Read, Fitton, and Hortton (2014), drawing-telling Desjardins and Wakkary (2011), design exposès Frauenberger, Makhaeva, and Spiel (2016), obstructed theater Mazzone, Iivari, Tikkanen, Read, and Beale (2010), persona Jones, Hall, and Hilton (2012), scenario-based design Vacca (2019), cool wall Bowen, Sustar, Wolstenholme, and Dearden (2013), blue sky Bowen et al. (2013), x-factor Bowen et al. (2013), dragons den Bowen et al. (2013), group sorter Soute, Lagerström, and Markopoulos (2013), context mapping Van Mechelen, Zaman, Laenen, and Abeele (2015), drama-based method Frauenberger, Makhaeva, and Spiel (2017)
Activity logging Nacher, Cáliz, Jaen, and Martínez (2018)	Monitoring, recording or tracking user actions such as the target of a click, hover event, current mouse position, etc. and nearly any other on-screen activity Atterer, Wnuk, and Schmidt (2006).	9.9	
Standardized questionnaires Metatla, Maggioni, Cullen, and Obrist (2019)	Usage of a previously validated and published questionnaire Boynton and Greenhalgh (2004).	5.4	Smileyometer Leite, Pereira, and Lehman (2017), Fun Sorter Sim and Horton (2012), Again-again Table Sim and Horton (2012), Self-assessment Manikin Metatla et al. (2019), Attrakdiff Fleck et al. (2018), Intrinsic Motivation Inventories (IMI) Harms, Cosgrove, Gray, and Kelleher (2013), Kids Game Experience Questionnaire (KidsGEQ) Martin-Niedecken (2018), PA Measure-Revised (MPAM_R) Ma et al. (2018), Playful Experiences Questionnaire (PLEXQ) Ma et al. (2018)
User testing Bateman, et al. (2018)	Users are invited to complete typical tasks with a product or simply asked to explore it freely while their behaviors are observed and recorded in order to identify design flaws that cause user errors or difficulties. The term is often used interchangeably with usability tests Bastien (2010).	4.7	Think aloud Leduc-Mills and Eisenberg (2011)
Diary keeping Sonne, Müller, Marshall, Obel, and Grønbæk (2016)	"Diary studies enable participants to record data in their own time, at particular times of day or when a particular trigger occurs. Diary entries may be more or less structured." Blandford et al. (2016)(pag. 46)	2.3	Memoline Sim et al. (2016)
Focus groups Gray, Robertson, and Rajendran (2015)	"The researcher typically takes a role as facilitator but the main Interactions are between participants, whose responses build on and react to each others'." Blandford et al. (2016)(p. 45).	2.3	

(*continued on next page*)

Table 2 (*continued*).

Type of method (with an example reference from our review)	Definition	%	Name of exact method, technique or tool (with an example reference from our review)
Cooperative Inquiry Garzotto (2008)	In the cooperative inquiry method, adults and children use a broad range of techniques to work together throughout the entire design process to create new technology Fails et al. (2012).	2.1	Sticky noting Kumar, et al. (2018), kid reporter technique Schaper et al. (2018), bags of stuff Yip, et al. (2019), Big Props Yip, et al. (2019), line judging Yip, et al. (2019), big paper technique Woodward et al. (2018), layered elaboration Yip, et al. (2016), mixing ideas Fails et al. (2019)
Free interview Liszio and Masuch (2017)	"A completely unstructured interview is more like a conversation, albeit one with a particular focus and purpose." Blandford et al. (2016)(p. 40).	2.1	
Prototyping Alhumaidan, Lo, and Selby (2018)	Prototypes are the "filters that traverse a design space" and the "manifestations of design ideas that concretize and externalize conceptual ideas" Lim, Stolterman, and Tenenberg (2008).	2	
Brainstorming Chu, Quek, Bhangaonkar, Ging, and Sridharamurthy (2015)	Brainstorming is a technique for fostering group creativity in which ideas and thoughts are shared among members spontaneously in order to reach solutions to practical problems Al-Samarraie and Hurmuzan (2018).	1	
Physiological measurements Antle, McLaren, Fiedler, and Johnson (2019)	Users' physiological signals can be used to assess their emotional experience while interacting with the product. Physiological measurements are signals which can be measured for living organisms (e.g. heart rate or skin conductance) Alexandros and Michalis (2013).	0.8	Eye-tracking Maqsood, Mekhail, and Chiasson (2018), emotion tracker Cerezo, Calderón, and Romero (2019)
Probes Brule et al. (2016)	(Cultural) probes gather qualitative data based on participatory user self-documentation. Cultural probes are a collection of tools, typically consisting of single-use cameras, user diaries, maps, postcards, or the like—each item added with some instructions on how to use it Thoring, Luippold, and Mueller (2013)	0.7	
Card sorting MoraGuiard and Pares (2014)	A methodology that can be used to capture users' mental models of how information is organized in a software interface. For software and website content, the results also lead to suggestions for navigation, menus, and possible taxonomies Chaparro and Hinkle (2008)	0.5	Picture Sorting Task Kory-Westlund and Breazeal (2019)
Other		3.1	Robotic Intervention Method Fransen and Markopoulos (2010), concept mapping Michaelis and Mutlu (2019), thought-listing technique Jones et al. (2012)
Not clear		0.3	

Table 3
Number of methods used in each paper (cumulative percentages).

Number of methods reported	1	2	3	4	5	6 or more
Distribution and cumulative percentage	$n = 272$ (100%)	$n = 182$ (66.9%)	$n = 93$ (34.1%)	$n = 43$ (15.8%)	$n = 17$ (6.2%)	$n = 7$ (2.5%)

creative sessions (6 out of 19) are the most preferred qualitative methods. Participatory design is also a common approach and is used as an umbrella term for many creative techniques in which children are actively involved in the design process (Nesset & Large, 2004). Although participation seems challenging for some user groups (e.g., children with ASD), new methods are continuously being developed to involve them in the research and design process, for instance the recently developed design critique tool (Frauenberger et al., 2013). In contrast, we observed that methods involving children with cerebral palsy more often involve gathering indirect feedback via methods such as activity logging or user tests (Saturno, Ramirez, Conte, Farhat, & Piucco, 2015). In general, we see a preponderance of mixed methods across all groups of children, with visually impaired children as the only exception.

4.6. An integrated understanding of research and design methods

In Fig. 9, we present an overview of all interaction design methods for children based on our selection of papers. We positioned the methods (gray circles) along two axes reflecting the different types of feedback children can provide and research vs. design-led methods (based on the coding scheme described in Section 3.4 point 4). The two dimensions are based on Druin's model (Druin, 2002), although we focused on children's relationship to adults, which we hereafter refer to as *feedback from children (coded as: indirect, feedback, dialog, elaborate)*, ranging from *passive to active*, and goals for inquiry (coded as: *theory, impact, usability*), which we hereafter refer to on a continuum from research to design-led (see Fig. 1).

The small black circles indicate examples of specific methods and/or techniques named by the authors of the reviewed papers. The size of the circle reflects the relative frequency of the method in all papers (e.g., user observation, at 23.9%, has a bigger circle

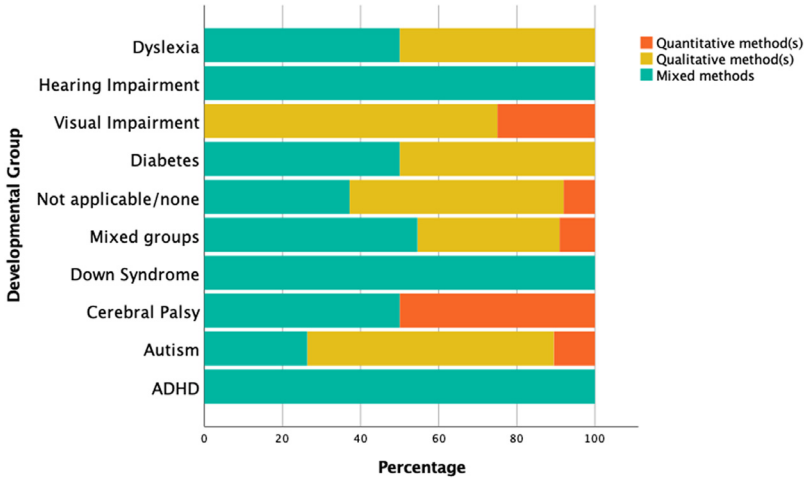

Fig. 8. Data triangulation across developmental groups.

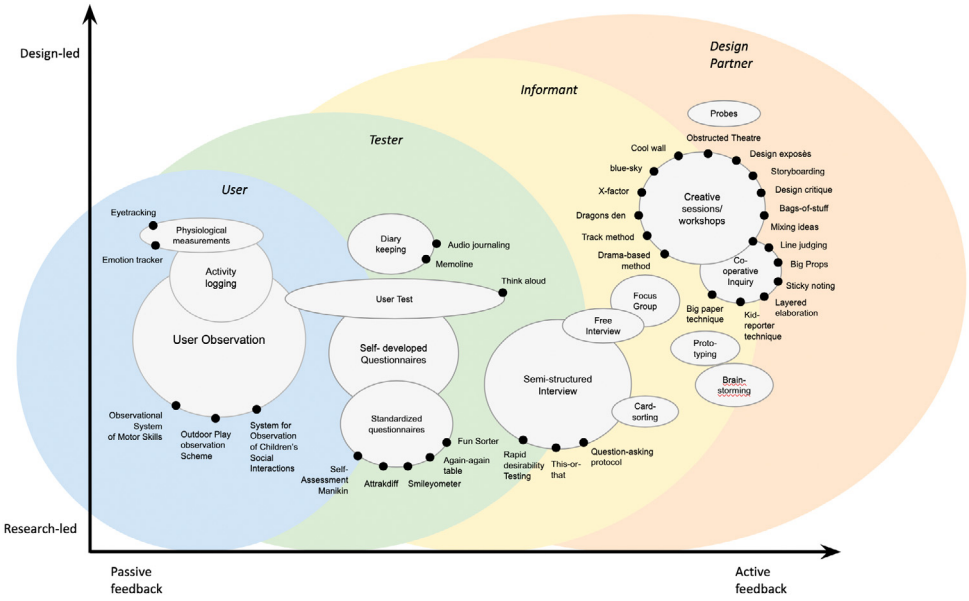

Fig. 9. Illustration of an integrated understanding of interaction design methods for children.

compared to semi-structured interviews, at 16%). User testing ranges from indirect feedback to verbal feedback, as different papers described different types of feedback provided by children. For methods such as creative sessions, children were mostly reported to be actively involved in the design process and therefore coded as having engaged in either dialog or elaboration within the feedback dimension. For probes-based methods (where participants typically engage with probe materials independently and in context), we considered the feedback provided by the children as very active, even though no researcher or adult was present during the time they were working with the probes. This is because the children actively engage with and elaborate on a tool or prototype to provide their feedback, for instance, by making video recordings. However, we clustered the methods in Fig. 9 based on the descriptions of the authors of the reviewed papers and not on our own understanding or interpretation based on other literature. Accordingly, Fig. 9 is based on empirical research rather than a methodological perspective, as was the case for Tsvyatkova and Storni (2019). The children's roles underlying this model (user, tester, informant, design partner) should not be understood as absolute, clear-cut distinctions, but rather orient the reader regarding on which side of the continuum a certain method could be placed. Therefore, we present the different children's roles as circles, similar to the onion model introduced by Druin (2002). In that model, as one moves along the continuum, roles represent a lower level of involvement. Thus, a tester can perform the roles of both tester and user, while a design partner can perform all roles (Druin, 2002).

4.7. Adult roles

Adults assumed different roles in the studies, which we coded based on the classification by Börjesson et al. (2015):

- *User:* a relative (e.g., sibling or parent) can also be the user of the technology developed.
- *Proxy*: people (e.g., parent, caregiver, teacher) surrounding the child are speaking for them.
- *Expert*: a professional (e.g., therapist, psychologist, teacher) aids in the design by speaking for a group of children. The difference to a proxy is that they do not seek to reflect a specific child's experiences.

- *Facilitator*: adults present during design activities to introduce the children and researchers or designers to each other, help build rapport, and provide practical assistance during the activity.

In addition to the roles described by Börjesson et al. (2015), we also coded whether the parents or legal guardians supported the children by e.g. escorting them to the testing location and waiting in a separate room. We called this role *support.* In the papers, mixed roles were most frequent (22.8%) (indicating any combination of roles, such as a parent acting as support while also help to facilitate the research), followed by the role of facilitator (12.1%), expert (10.7%), user (9.9%), proxy (3.3%) and support (1.5%). In 28 papers, we could not identify an adult role. Moreover, we found a relationship between different adult roles and the children's developmental group. We can see in Fig. 10a that the role of expert is dominant for children with dyslexia, visual impairment, and Down Syndrome. Other developmental groups, such as diabetes or Autism Spectrum Disorder, have a wider spectrum of adult roles. In the mixed and typically developing groups, we see the widest variety of roles applied. In addition, Fig. 10b shows that some adult roles are linked to the type of feedback children provide. The role of facilitator is often taken in methods where children have to provide active feedback. Adults take the role of expert more often in combination with verbal or passive feedback from children. Adults are least involved when children are asked to provide written feedback. In general, we observed a strong tendency towards mixed adult roles across all types of feedback.

Furthermore, we were interested in the correlation between children's age and the roles adults take in the different papers. A point-biserial correlation was calculated to determine the relationship between the children's median age and adult roles. There was a positive correlation between age and adult role, which was statistically significant ($r_{pb} = .138$, $n = 272$, $p = .028$). Three outliers are included in the figure, from left to right, representing papers numbered 190, 27, and 241). We did not exclude those three papers with a mean age above 18 years from further analysis, as argued in more detail in our exclusion criteria in Section 3.2 . In the very active adult role as proxy (e.g. speaking for a child), the median children's age is significantly lower compared to the other adult roles (see Fig. 11).

4.8. Ethics in research with children

Informed consent was reported in 42.7% of the papers. 19.5% state having received consent from parents only, 3.3% from children only, and 19.9% from both children and parents. In 56.6% of papers, no information or unclear information was provided about informed consent. Moreover, we counted the number of papers that reported ethical approval. Only 21% did report ethical approval, 1.8% clearly stated that they had not received ethical approval, and for 76.5% of reports, it was not clear whether ethical approval had been received or not.

5. Discussion

This systematic review of interaction design methods for children is based on a sample of 272 full empirical papers published in predominant venues in this field. We aimed to provide a comprehensive overview of methods used in the CCI field by surveying methods addressing the complete age range of childhood and adolescence (0–18 years), including developmentally diverse children, addressing stakeholders' roles and looking at methods and data triangulation patterns. In this section, we discuss future research challenges, which could serve as a guide for upcoming research in the CCI field.

5.1. Evolution of CCI methods

We identify an increasing number of CCI papers over the past 15 years, with conference proceedings from IDC and CHI the predominant publication venues. In terms of research locations, we found a strong tendency for natural settings, especially in the educational context (e.g., schools, preschools), compared to laboratory environments. As already noted in 2004 by Jensen and Skov (2005), the preference for natural settings prevails due to the usefulness and necessity of examining a product solution in a real-world environment. However, the lack of a controlled setting in the real world has led some researchers to prefer a controlled laboratory environment (Kjeldskov & Graham, 2003). The preference for natural settings is not surprising considering the types of products that are most commonly studied according to our review, namely interactive games and mobile applications. Such products lend themselves to investigation in the field, which can be essential in order to learn more about their usefulness and usability in realistic conditions. Similar to product categories for the adult population, where the most frequently studied products are mobile phone/applications and interactive games, newer technologies such as connected services/IoT and VR/AR have attracted increased interest over the past couple of years (Pettersson et al., 2018). However, these new technologies have not yet been used to support the evaluation of products or systems, which might be a future usage scenario. Furthermore, approximately half of the studies conducted in a natural setting evaluated a product or system at one moment in time (cross-sectional studies), compared to 41.9% that evaluated it several times (longitudinal studies). Pettersson et al. (2018) observed a positive trend since 2010 for the adult population in this regard, so we might expect similar perspectives for the child population.

In terms of method triangulation, we observed a trend towards the use of more methods within the same study, as more than three-quarters of papers applied at least two methods and 34% at least three methods. Similar results were found for the adult population, with 72% of all papers using a triangulation approach (Pettersson et al., 2018). The majority of papers in our study used a mixed-methods approach (qualitative and quantitative), which is not surprising when considering the arguments for applying triangulation, i.a. addressing the same problem from different angles to derive a fuller understanding of the problem and ultimately strengthen the results (Börjesson et al., 2015), or to "gain deeper insights". Pettersson et al. (2018) mentioned yet another reason for triangulation, which is to better understand the results of other applied methods, e.g., using post-use interviews to make sense of observations. However, looking at the specific triangulation patterns outside the mixed-methods approaches, we saw that traditional and more research-led methods are often applied together, whereas we did not see the same trend for design-led methods. The focus seems to be on the conventional end with the research-led methods on one side of the coin and the design-led on the other. This might be due to resource constraints, or that design processes tend to be presented in a linear fashion, from a selected design method to a resulting design. There seems to be some uncertainty in the field as to what could be suitable combinations outside of traditional methods. Of the surveyed methods, user observation, interviews and questionnaires have the longest history, tracing back to early work in the humanities, which might explain why they are applied together most often (Pettersson et al., 2018).

As a new and interdisciplinary field, CCI has contributed to the development of participatory design methods, which are found in the design-led area with active user involvement (Kawas, et al., 2020). The framework by Kawas, et al. (2020) illustrates this melting pot of approaches and methods. However, an open question concerns which methods qualify for triangulation and why.

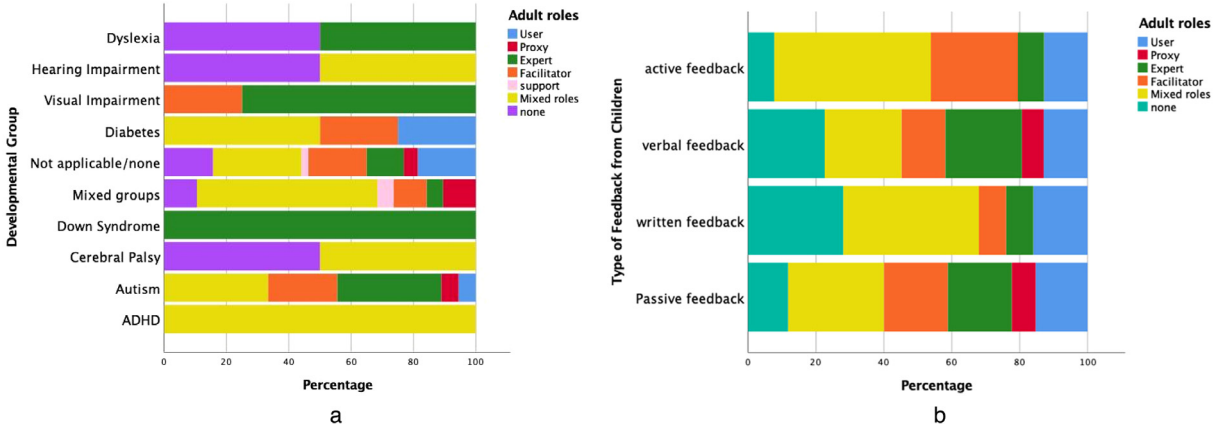

Fig. 10. (a) Relation between children's developmental group and adult roles. (b) Relation between type of feedback gathered from children and adult roles.

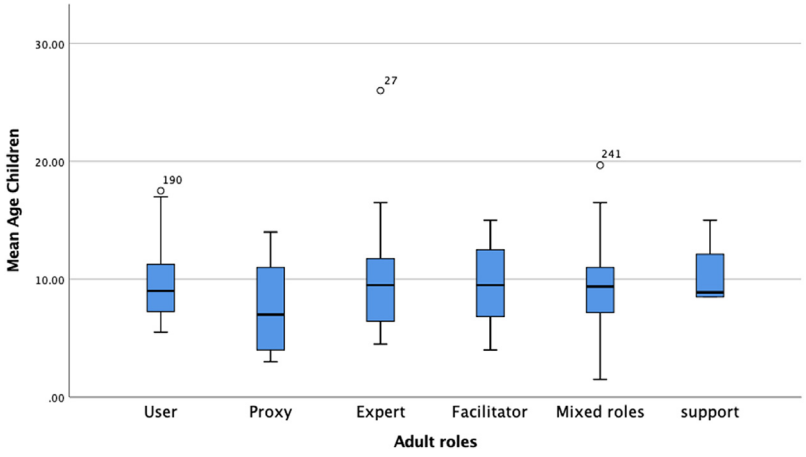

Fig. 11. Boxplot representing the relation between adults' roles and children's age.

We therefore suggest that researchers go beyond data triangulation in general, with its obvious advantages (such as in terms of reliability) and instead look for new triangulation patterns along the two intersecting dimensions of design vs. research-led approaches and different levels of user involvement (from passive to active) (see Fig. 9). An example could be to combine cooperative inquiry (design-led, active feedback) with standardized questionnaires (research-led, passive/written feedback). Combining research-led and design-led methods could, for instance, help design-led inquiry avoid confirmation bias and premature commitment, similar to the advantages of a mixed-methods approach (Pettersson et al., 2018). Furthermore, since design is contextual by nature, any attempt to generalize lessons learnt would benefit from a complementary research-led inquiry. This would allow us to extend our understanding by looking at the same problem from different perspectives, providing further inspiration for the development of technologies and products. However, exploring new method combinations remains a challenge, as many researchers might favor what has worked from them in the past.

5.2. Perspectives for diverse developmental groups

This review is the first to examine CCI methodology addressing the whole child population from 0 to 18 years, including developmentally diverse children. Similar to other reviews (Tsvyatkova & Storni, 2019; Yarosh et al., 2011), we see that not all age groups are evenly involved in the research and design process. Children between 7 and 13 years old (see Fig. 1) are predominantly represented, while younger and older age groups have received less attention. This age focus seems independent of developmental group, as Yarosh et al.'s (2011) findings indicate that typically developing children are generally between 6 and 12 years old, while developmentally diverse children involved in design are also within this age range (Tsvyatkova & Storni, 2019). We believe that by including children of different ages and from diverse developmental groups, we can provide a broader and more realistic picture of the current state of the art within the CCI field and can make explicit methodological advances that cut across developmental groups.

As such, we investigated sequential triangulation across different user groups, observing that qualitative methods are more often applied than quantitative methods for most user groups (see Fig. 8). Similarly to other studies (e.g., Börjesson et al., 2015), we found that research methods with ASD children are more varied. In addition, research with ASD children applies methods from the participatory design field, a common approach and umbrella term for many creative techniques in which children are actively involved in the design process (Nesset & Large, 2004). Although this seems challenging for children with ASD, new methods are continuously being developed to involve them in the research and design process, such as the recently developed design critique tool (Frauenberger et al., 2013). In contrast, we observed that methods involving children with cerebral palsy more often involve gathering indirect feedback from methods such as activity logging or user testing (Saturno et al., 2015), which is also in line with (Börjesson et al., 2015), who found user testing to be a dominant method along with prototyping and post-experience interviews. In general, we also see a mixed-methods trend within

all groups of children, with visual impairment the only exception, which might be due to the low number of studies found for that group.

The most variation in method application was found in the typically developing group, which again might be due to the higher number of papers analyzed for this group (75.3%). Given the predominance of typically developing children in recent research, we believe that the field should strive for greater inclusion when consolidating its methods. Most real-world technologies are not solely designed for one particular user group, and many school systems group developmentally diverse children together in inclusive classrooms. So why are we not developing methods that suit the needs of all children? Some authors state that different groups of children might require different approaches, such as providing a clear structure in the sessions, and different levels of active participation by caregivers, teachers and therapists based on different groups of children's unique needs (Börjesson et al., 2015). Linking different methods to particular skill sets children should possess, such as writing or expressing themselves verbally, could help with the selection of a suitable method. Another fruitful approach might be to investigate the environment in which children reside instead of focusing solely on their disability (Börjesson et al., 2015). We believe the first step in this direction can be taken by formulating appropriate alternatives to current methodologies by defining the rationale underlying each option and the specific user and usage description of context characteristics. We hope that the selection of appropriate methods will profit from this approach and create awareness of the benefits of employing heterogeneous methods. We do not suggest a *one-size-fits-all approach,* but wish to stimulate discussion about *whether* and *how* our methods are applicable for diverse populations of children, with the overarching goal of informing researchers of how a particular method can be used in different contexts, with different groups of children and stakeholders. Consequently, we could think about how the methods proposed for a specific research group could apply to different populations, whether developments and evidence have been replicated for different groups, and if the methods that are most commonly adapted to serve specific groups share certain characteristics.

5.3. Children's and adults' roles

It seems that work with some developmentally diverse groups does not follow the generally observed preference for active user involvement and instead relies on more classical approaches with a lower level of user involvement (e.g., indirect and written feedback) (Börjesson et al., 2015). Scholars researching the different roles taken by typically developing children in more detail have found that children are actively engaged in the ideation phase of design, whereas during evaluation, they are mainly considered as final users (Landoni, Rubegni, Nicol, & Read, 2016). For developmentally diverse children, previous reviews have indicated that such children have been involved in a range of activities in several phases of the design process (Börjesson et al., 2015), which might indicate an active involvement overall. However, several papers also mentioned the difficulty of involving developmentally diverse children as design partners (Keay-Bright, 2007; Menzies, 2011). We found a relation between adults' roles and the types of feedback children provided. The facilitator role, representing the lowest degree of intervention by an adult, seems the most dominant across all types of feedback, but had the strongest relation with active feedback by the children. In contrast, more intervention by adults, for instance as an expert, is associated with the more passive involvement of children. As stated earlier, the methods that aim to place less of a burden upon children by studying them passively tend to have a greater research focus. In this context, it is also interesting to observe that the children's age has an influence on the roles adults take in the design process. However, the question remains open at this stage as to whether adults adopt certain roles based on the methods selected, or whether certain methods are selected because they are associated with certain adult roles. Overall, we see a strong potential benefit from studies that move away from the expert mindset in the direction of a participatory mindset, as we have seen an increasing trend of methodological developments in that area. It may be erroneously assumed that moving away from an expert mindset reduces the research focus. At this stage, we cannot answer the question of why this trend appears and why we are not seeing a research-led focus combined with a participatory mindset, as defined in the design research map by Sanders (2008). However, we would like to encourage future researchers to rethink the roles of adults throughout the design process and more actively make use of the wide spectrum of roles available. We also hope that researchers work to create a better balance of power relations by experimenting with new methods in the area of research-led and participatory mindset that would give children a stronger voice.

5.4. Reporting on the code of ethics

The salience of ethical issues when working with vulnerable groups such as children is not a new challenge. Consequently, we are rather concerned about this review's finding that more than half of papers did not report on informed consent and 76.5% did not report if they had received ethical approval to conduct the study. This finding is similar to a recently conducted systematic review of the top four conferences in the field of Human–Computer Interaction in the years 2018 and 2019, including the Conference on Human Factors in Computing Systems (CHI) (Van Mechelen et al., 2020). For CHI, 24.6% of papers mentioned an IRB or ethics committee review, similar to the 21% we found for our reviewed papers (Pater et al., 2021). Applying and reporting ethical procedures should not be a pragmatic choice, nor should we blindly assume that researchers must have fulfilled their duty. We as researchers have a responsibility to answer certain fundamental questions concerning the risks and burden to participating children. Some of the main conference venues for publishing interaction design work with children, such as the ACM Interaction Design and Children Conference, have formulated a strict requirement to include a special note on ethics and children in all research papers from 2018 onwards, following the adoption of the European Union's General Data Protection Regulation (GDPR) (Calder, 2017). In this note, paper authors should state how the participating children were selected, what consent processes were followed (e.g., did they consent and if so, what they were told), how they were treated, how data sharing was communicated, and any additional ethical considerations. The GDPR has also contributed to shaping the ACM Code of Ethics, as Principle 1.6 "Respect privacy" now includes a call for a more general requirement for informed consent procedures (Gotterbarn, Bruckman, Flick, Miller, & Wolf, 2017). According to the ACM, informed consent procedures should go beyond ensuring that users understand what data is being collected and used; they should actually give them the ability to consent or withhold consent from data collection. Informed consent should ideally be a proactive agreement with the user about the type, content, and usage of data collected about them (Gotterbarn et al., 2017). Van Mechelen et al. (2014) developed CHECk, a value checklist created for use prior to and at the start of design activities to help CCI researchers critically consider their values when involving children in design projects and examine how best to explain participatory design activities to children to aid informed consent. These developments are promising; however, we strongly

encourage CCI researchers to pay sufficient attention to ethical issues when working with children. The successful application of a code of ethics should reflect the values of our community in a way that can help researchers make appropriate ethical decisions.

6. Limitations

This review had several limitations. First, when searching for relevant publications according to the defined search query, we narrowed our scope down to two main databases (ACM and Scopus). Our analysis might thus have missed relevant papers, such as papers conducted within disciplinary backgrounds not typically referenced in ACM and Scopus. We also required the presence of "child" or related keywords (as presented in Table 1) in the title, which might exclude some papers from specialized venues such as IDC, which do not require children to be mentioned in the title. We also only cover published literature in the English language, as the language of international research. Community-specific approaches published in other languages might also have been overlooked. Second, due to the ambiguity of what is considered by the authors themselves as a tool, a method and a technique, we did not distinguish between those terms in our analysis. Third, even though the first two authors worked together to double-code a number of papers, from which we calculated the interrater reliability, and the third and fourth authors did an independent cross-check on a sample of papers, most papers were single-coded by the first author. This might have introduced some bias. However, discussing uncertainties and cross-checking the coding scheme with independent researchers in the field helped to further reduce bias in the interpretation of some codes. Finally, the interpretation of results related to diverse developmental groups should be taken with caution, as some of those groups were represented in a limited number of papers. For instance, only one study involving children with ADHD was included in the review.

7. Conclusion

In this paper, we conducted a structured literature review to examine the state of the art in interaction design methods for children. Our final corpus consisted of 272 empirical papers. Based on our analysis, we built a systematic understanding of recent empirical methodologies in the CCI field. Our results indicate a preference for conducting field studies, mainly focusing on product categories such as interactive games and professional software. Furthermore, we observed an increase of studies focusing on newer technologies such as VR/AR in recent years and identified a preference for evaluating products repeatedly over time, with more than half of researchers applying a combination of two or more methods to design or evaluate their product. However, as we found that combining various research-led methods, such as user observation and semi-structured interviews, was most common, we would like to challenge future research to look for new combinations of methods across the wide continuum of research- and design-led approaches by, for instance, mixing different roles of stakeholder involvement. The challenges reported in former reviews published in the field also emphasizes the need for more methods and activities suitable for children of younger ages and diverse abilities (Spiel et al., 2019), which is also in line with our findings. A strong effort to develop more methods in the participatory design area, such as creative sessions with children, is also clearly visible, especially when looking at the development of new tools and techniques. It seems desirable for this trend to continue into the future and be extended to all developmental groups. Along with this, we would like to draw attention to the need to establish best research practices (Spiel & Gerling, 2021) by reporting ethical procedures when involving children in the research and design process. With this in mind, we look forward to future trends and challenges in the application of CCI methods towards a truly child-centered approach.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Selection and participation

This manuscript is a review paper and did not select or include any participation of children.

Appendix A. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.ijcci.2021.100398.

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