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Data handling practices and commercial features of apps related to children: a scoping review of content analyses

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ABSTRACT

Background Child interaction (including via parent proxy) with mobile apps is common, generating concern about children's privacy and vulnerability to advertising and other commercial interests. Researchers have conducted numerous app content evaluations, but there is less attention to data sharing or commercial practices.

Objective This scoping review of commercial app evaluation studies describes the nature of such evaluations, including assessments of data privacy, data security and app-based advertising.

Methods We searched Scopus, PubMed, Embase and ACM Digital Library (2005–2020). We included studies that evaluated the properties of apps available through commercial app stores and targeted children, parents of a child (0–18 years) or expectant parents. Data extracted and synthesised were study and app user characteristics, and app privacy, data sharing, security, advertisement and in-app purchase elements.

Results We included 34 studies; less than half (n=15; 44.1%) evaluated data privacy and security elements and half (n=17; 50.0%) assessed app commercial features. Common issues included frequent data sharing or lax security measures, including permission requests and third-party data transmissions. In-app purchase options and advertisements were common and involved manipulative delivery methods and content that is potentially harmful to child health.

Conclusions Research related to the data handling and the commercial features of apps that may transmit children's data is preliminary and has not kept pace with the rapid expansion and evolution of mobile app development. Critical examinations of these app aspects are needed to elucidate risks and inform regulations aimed at protecting children's privacy and well-being.

What is already known on this topic?

⇒ Mobile app developers encourage users to enter personal information and routinely share collected data with third parties to enhance the user experience or monetise the app.
⇒ Apps focused on children may be among the worst in terms of the number of associated third-party data trackers—posing privacy and safety concerns to children.
⇒ Child and parent app content analyses are increasingly conducted, but little is known associated data privacy, data security and app-based advertising assessments.

What this study adds?

⇒ Comprehensive evaluations of the data privacy and security elements and commercial features of apps that may transmit children's data are rarely conducted.
⇒ When evaluated, child and parent apps show frequent data sharing and lax security measures, including permission requests and third-party data transmissions.
⇒ In-app purchase options and advertisements appear common in child and parent apps and involved manipulative delivery methods and content that is potentially harmful to child's health.

INTRODUCTION

Today's children are growing up in an immersive digital media era where frequent interaction with mobile applications (apps) is the norm. In addition to their own use of technology, children's data including photographs, videos and personal information are shared via their parents' online behaviours. Engagement with technology spans childhood, with 49% of parents using parenting apps,[1] 60% of children less than 3 years having used a mobile device[2] and, in the UK, 53% of children aged 7 years and 90% of children aged 11 years reporting mobile phone ownership.[3] Unfortunately, children and their parents are generally engaging with apps without a fulsome understanding of the privacy implications of their actions or the commercial interests in monetising their app-based activities.[4]

Mobile app developers encourage users to enter personal information and routinely share collected data with third parties to enhance the user experience or commercialise the app.[5] Adult apps are known to share personal and health information with an array of commercial entities, which are then capable of aggregating data across apps and re-identifying users.[6 7] Recognising children's particular vulnerabilities, regulations designed to protect child privacy include Europe's General Data Protection Regulation (GDPR) and the United States' Children's Online Privacy Protection Act (COPPA). These regulations require operators of online services such as apps to give detailed notice of privacy practices and prohibit the processing of children's personal information without consent.[8 9]

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Still, evidence suggests that apps containing children's data are among the worst in terms of the number of associated third-party trackers[10]—and developers may skirt privacy regulation by claiming their app is targeted at general audiences rather than children.[11]

This mobile ecosystem and current regulatory situation creates serious risks to children. The ubiquitous online presence and purchasing power of young parents and children mean these groups are now at the centre of the e-commerce market. This is highly problematic as serious child privacy and safety issues may arise if information shared with apps is used for data-driven advertising. Furthermore, there is a real danger that data aggregators may create digital dossiers that follow young people into adulthood and impact their future education, employment and health insurance acquisition opportunities.[12]

In parallel with these data handling issues, research attention has increasingly turned to app stores and the content and quality of commercially available apps. Given the availability of such evaluations and that these apps may transmit child data to a host of third parties, the objective of this review was to understand the scope of such evaluations, including whether and how researchers are assessing data privacy, data security and app-based advertising and what results they are finding in these areas.

METHODS

Design and reporting

We conducted a scoping review according to the framework developed by Levac *et al*[13] using an internal protocol that was based on a previous, similar review by a member of our group.[14] Review reporting is in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) extension for scoping reviews (PRISMA-ScR) checklist.[15]

Eligibility criteria

We included studies that evaluated apps available in commercial stores which collected data directly related to children; thus users would be children, a parent of a child (0–18 years) or an expectant parent. We excluded commentaries, topical or systematic literature reviews, protocols, book chapters and conference abstracts. No language restrictions were placed. The search was limited to studies published from 2005 onward—the timeframe where mobile apps have been publicly available.[16]

Information sources and evidence screening

On 18 November 2020, we conducted searches in the Scopus (Elsevier), PubMed, Embase (Ovid) and ACM Digital Library databases. Our search strategy was developed in consultation with a research librarian (online supplemental appendix 1) and piloted to validate applicability. We supplemented the search with searches of our own databases of mobile app literature. Using Covidence software, duplicates were removed and three authors independently screened titles and abstracts, and then full texts, in duplicate according to the eligibility criteria. Eligibility disagreements were resolved through discussion with a third reviewer.

Data charting

We developed, piloted and refined a data charting table with reference to those used in our previous research in this topic area[14 17] and we charted data into this table. The data items charted are shown in online supplemental appendix 2.

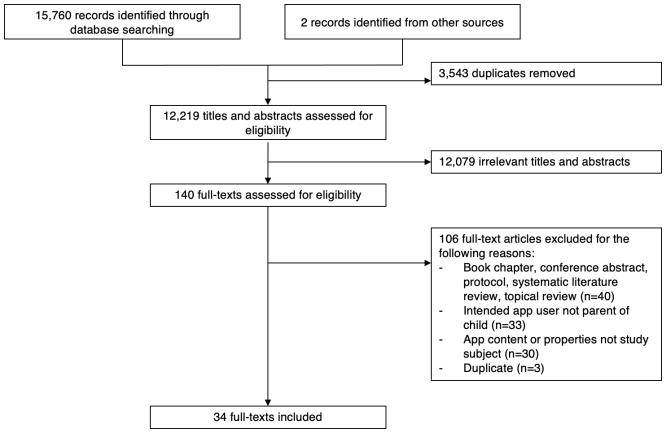

Figure 1 Study selection process.

Synthesis of results

Data abstraction fields were grouped according to key data features to enable synthesis. Quantitative data were summarised using descriptive statistics. Where appropriate, qualitative data items were categorised descriptively, and frequencies calculated. Charting and categorisation were conducted by one author and checked by a second author.

RESULTS

Study selection

We identified 15 762 records across all databases (figure 1). After the removal of duplicate and screening of titles and abstracts, we assessed 140 full-text articles for inclusion. Following full-text screening, 34 articles were included in this review.

Study and general app characteristics

The number of published studies meeting our inclusion criteria has increased over time (figure 2). Study details are shown in table 1. Studies were conducted in the USA (n=18; 52.9%), Australia (n=9; 26.5%), Canada (n=2; 5.9%), Iran (n=1; 2.9%), India (n=1; 2.9%) and the UK (n=1; 2.9%). Two studies (5.9%) were conducted across multiple countries. Most commonly, study designs were reported as systematic reviews or evaluations (n=13; 38.2%), descriptive or content analyses (n=10; 9.4%), or reviews (n=5; 14.7%). Stated designs represented the authors' own labelling, and we did not find meaningful correspondences between reported study designs and the methods used. Study funding was from government agencies (n=10; 29.4%), universities (n=3; 8.8%), non-for-profit organisations (n=1; 2.9%), for-profit organisations (n=1; 2.9%) or a combination of these sources (n=5; 14.7%). Nine studies (26.5%) did not identify the funding source and 5 (14.7%) received no funding.

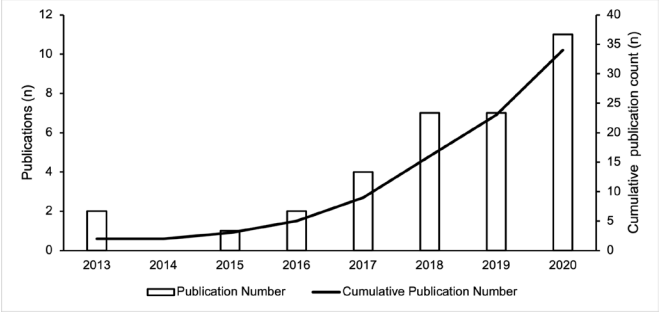

Figure 2 Study publication number over time.

Table 1 Study and associated app sample characteristics

First author and year	Country of origin	Reported design	Funding source(s)	Target user	Targeted user characteristics	App stores searched	App store search date(s)	Method for app sampling	App sample number	App sample language restriction	Children's app content
Biviji *et al* [39]	USA	Review and content analysis	None	Parents	Pregnant people, future parents, other caregivers of infants	Apple App and Google Play	Not reported	Scraping software	29	English	Pregnancy or early childhood health education or user decision-making support functions
Biviji *et al* [40]	USA	Cross-sectional report	Combination	Parents	Parents-to-be, other caregivers of infants	Apple App and Google Play	March 2017	Scraping software	421	English	Pregnancy or early childhood health education or user decision-making support function
Bland *et al* [41]	UK	Content analysis	Combination	Parents	Pregnant people	Apple App and Google Play	November 2018	Keyword	29	English	Pregnancy-specific nutritional support functions
Brown *et al* [42]	Australia	Review	None	Parents	Pregnant people	Apple App	October 2017	Keyword	51	English	Nutrition or dietary information
Bry *et al* [43]	USA	Systematic evaluation	Not reported	Parents or children	Children with anxiety, parents of a children with anxiety	Apple App and Google Play	February 2016	Keyword	121	English	Anxiety-related symptom treatment or management
Chen *et al* [44]	USA	Systematic review	For-profit	Children	Adolescents and young adults who are sexually active	Apple App and Google Play	July 2015	Keyword	22	English	Pregnancy prevention information
Cheng *et al* [24]	Australia	Systematic evaluation	Not reported	Parents	Parents of infants up to 1 year	Apple App and Google Play	September 2018 to January 2019	Keyword	47	English	Milk feeding behaviours, solid food feeding behaviours or infant activity information
Das *et al* [20]	USA	Content analysis	Government	Children	Children or adolescents under the age of 18	Apple App and Google Play	March 2016	Store-reported highly ranked apps	64	Not reported	All app content types included
Davis *et al* [45]	USA	Content analysis	Not reported	Parents	New parents	Apple App	2016	Keyword	46	English	Parenting, infant health or child health information
Furlong *et al*[46]	Australia	Systematic review	Government	Children	Children up to 12 years old with a speech disorder	Apple App and Google Play	November 2016 to May 2017	Keyword	132	English	Includes tasks that require production of speech by user
Hotwani *et al*[47]	India	Content analysis	Not reported	Parents or children	All children	Apple App	Not reported	Keyword	6	English	Tooth brushing promoting functions
Hswen *et al* [48]	USA	Content analysis	Not reported	Children	Children aged 4 and older	Apple App	March 2012	Store-reported highly ranked apps	20	Not reported	All app content types included
Liu *et al* [22]	USA	Not reported	Government	Children	All children	Google Play	April 2015	Classifier software	67 778	Not reported	All app content types included
Meyer *et al* [23]	USA	Content analysis	University	Children	Children less than 5 years old	Google Play	December 2017 to March 2017	Store-reported highly ranked apps	135	Not reported	All app content types included
Mousavi *et al*[49]	Iran	Systematic review	None	Parents or children	All parents or children	Apple App and Google Play	December 2017	Keyword	4	English	Health monitoring, health decision support and diagnosis support functions
Musgrave *et al*[50]	Australia	Systematic review	University	Parents	Pregnant people	Apple App and Google Play	November 2017 to October 2019	Store-reported highly ranked apps	10	English	General pregnancy information
Quinn *et al* [51]	USA	Not reported	None	Children	Children preschool and/or kindergarten age	Apple App and Google Play	Not reported	Keyword	472	English	Handwriting, spelling and/or composing training
Reyes *et al* [18]	Multiple	Content analysis	Combination	Children	Children less than 13 years old	Google Play	November 2016 to March 2018	Scraping software	5855	English	All app content types included
Richardson *et al*[52]	Canada	Systematic review	Government	Parents	Parents of children in the NICU (inclusive of guardians, additional family or individuals that provide care to infants in the NICU)	Apple App and Google Play	2017	Keyword	18	English	Information or support functions for parents of infants in NICUs

Continued

Table 1 Continued

First author and year	Country of origin	Reported design	Funding source(s)	Target user	Targeted user characteristics	App stores searched	App store search date(s)	Method for app sampling	App sample number	App sample language restriction	Children's app content
Robinson *et al*[53]	USA	Content analysis	Government	Children	Smoking adolescents attempting to quit	Apple App and Google Play	November 2016	Keyword	46	Not reported	Smoking cessation education
Sardi *et al* [21]	Multiple	Systematic review	Government	Parents	Postpartum women	Apple App and Google Play	January 2019	Keyword	48	English	Postnatal care support functions for the mother and/or newborn
Schoeppe *et al*[54]	Australia	Systematic review	Combination	Children	All children and adolescents	Apple App and Google Play	May 2016 to November 2016	Keyword	25	English	Diet, physical activity and sedentary behaviour improvement functions
Schoffman *et al*[55]	USA	Systematic evaluation	None	Children	Children and adolescents with obesity	Apple App and web search	June 2012	Keyword	57	English	Weight loss/healthy eating/physical activity support functions
Sidhu *et al* [56]	USA	Content analysis	Government	Parents	Breastfeeding mothers of infants 0–6 months	Apple App and Google Play	August 2017 and October 2017	Keyword	41	English	Breastfeeding education or breastfeeding experience tracking
Taki *et al* [57]	Australia	Systematic evaluation	Government	Parents	Parents of infants up to 1 year	Apple App and Google Play	December 2013, March 2014, and December 2014	Keyword	46	English	Healthy milk or solid food feeding behaviour information
Virani *et al* [58]	Canada	Review	Not reported	Parents	All parents	Google Play	June 1 2018	Keyword	16	English	Parenting information and support functions
Weber *et al* [59]	USA	Review	Government	Parents	Participants in a special supplemental nutrition programme for women, infants, and children	Apple App and Google Play	December 2017 to June 2018	Keyword	17	Not reported	Relating to the supplemental nutrition programme from women, infants and children
Weekly *et al* [60]	USA	Review	Not reported	Parents or children	Palliative paediatric patients, caregivers of palliative paediatric patients	Apple App, Google Play and Blackberry World App	May 2017 to July 2017	Keyword and expert referral	16	English and Spanish	Mindfulness, relaxation or distraction education or training
Wisniewski *et al*[61]	USA	Systematic evaluation	Government	Parents or children	All parents or children	Google Play	April 2016 to May 2016	Keyword	75	Not reported	Adolescent online safety functions
Womack *et al*[62]	USA	Content analysis	Not reported	Parents	Pregnant people	Apple App and Google Play	November 2015	Keyword	48	English	Pregnancy information
Zarnowiecki *et al*[63]	Australia	Systematic review	Not-for-profit	Parents or children	Parents of children under 15, children under 15	Apple App and web search	October 2018 to November 2018	Keyword	4	Not reported	Meal planners, shopping list or lunchbox functions
Zhao *et al* [25]	Australia	Comprehensive assessment and exploratory qualitative research	University	Parents	Parents of infants and young children	Apple App and 360 Android Mobile Assistant	April 2016	Keyword	26	Accessible in simplified Chinese characters	Healthy infant feeding provision functions
Zhao *et al* [26]	Australia	Not reported	Not reported	Parents	Mothers of children 3 years of age and less or mothers-to-be	360 Android Mobile Assistant	February 2018	Store-reported highly ranked apps	79	Accessible in simplified Chinese characters	Pregnancy and early parenting information or support functions
Zhao *et al* [19]	USA	Prospective cohort study	Combination	Children	Children aged 3–5 years	Google Play	August 1 2019 to November 1 2019	Parent list of used apps	451	Not reported	All app content types included

NICU, neonatal intensive care unit.

The median app sample size across studies was 46 (range 4–67 778). Parents were the intended app users in 16 studies (47.1%), children in 12 studies (35.3%), and parents or children in 6 studies (17.6%). Apps were most commonly available through both iTunes (Apple) and Google Play stores (n=19; 55.9%)—followed by Google Play (n=6; 17.6%) or iTunes alone (n=4; 11.8%). To sample apps, authors most commonly used keyword searches in app stores (n=23; 67.6%), store-reported ranking lists (n=5; 14.7%) or software to support searching of app store contents (n=4; 11.8%).

App data privacy and security-related findings

Less than half (n=15; 44.1%) of the studies evaluated any data privacy or security features. A total of two studies (5.9%) evaluated apps' third-party data sharing practices.[18 19] In both cases, studies automated the process of app execution using simulated data inputs and determined the number and domain destination of data transmissions. Results showed that 67%[19] and 73%[18] of apps transmitted children's personal data to third parties including those providing advertising-related services. Transmitted data included email addresses, information enabling user geolocation and advertising IDs that can be used to create behaviour profiles for advertising. Third-party transmission counts were not associated with child sex, parent age or marital status, or family income-to-needs ratio. However, transmissions were twofold to threefold higher in the case of children whose parents did not have advanced degrees.[19]

Table 2 shows other app privacy-related and security-related evaluation data from studies. Eight studies (23.5%) reported on apps' capacity to share information via social media. These studies did not explicitly evaluate whether the nature of such sharing was active (ie, user-initiated data sharing for purposes including seeking peer support) or passive (ie, data transmission to social media networks unbeknownst to the app user). The potential to share data to social media platforms occurred in 14%–63% of apps (median 28%).

Additionally, three studies (8.8%) documented the presence of privacy policies and single studies (2.9%) evaluated each of privacy policy content and readability. These studies showed 5%–100% of apps (median 63%) had an associated privacy policy. Policy readability was poor[20] and often failed to comply with international or federal regulations.[21] Two studies (5.9%) documented actual or potential permission requests,[22 23] showing that permission requests occurred in up to 100% of apps and may violate jurisdictional privacy regulations such as location data tracking.

App data security features were evaluated in 29.4% (n=10) of studies and included presence of login or password protection element (n=7; 20.6%), login/password and cloud storage option (n=1; 2.9%), or data encryption (n=1; 2.9%), and the application of an investigator-developed security assessment scale (n=1; 2.9%). Security-related results showed: login or password protection presence in 0%–100% of apps (median: 31%), high proportions of apps not protecting data transmissions using standard methods,[18] and few apps with high security assessment scale ratings.[24]

App commercial feature-related findings

Commercial features were assessed in 17 studies (50.0%) (table 3) and included the proportion of apps with in-app purchase options (n=15; 44.1%), the proportion of apps with in-app advertisements (n=10; 29.4%) and the type of advertisements (n=3; 8.8%). In-app purchases and advertisements were present in 0%–46% (median 25%) and 9%–95% (median 51%) of apps, respectively. To evaluate advertisement content, all studies used manual content analysis using a predefined and investigator-developed advertising coding scheme.[23 25 26] Content analysis conducted by Meyer *et al*[23] showed advertisements were presented using traditional methods (eg, product videos as shown on television) but also in insidious ways that might prompt further advertising consumption (eg, embedding advertising videos within gamified app features). In the two studies that assessed the relationships of advertisements to health outcomes, advertisements promoted formula-feeding for premature babies, toddlers or older children,[25 26] which may be in contravention of the WHO Code on the Marketing of Breast Milk Substitutes[27] due to potentially harmful impacts on health.

DISCUSSION

Evaluations of the content and quality of commercially available apps that may transmit child data have proliferated steadily over time. Rigorous, independent evaluations of the data sharing practices and commercial features of these apps remain rare. However, there is rapid methodological development in the field and strategies to evaluate these practices are being increasingly developed and used by interdisciplinary research groups.[10 18 19]

Study and app characteristics

Reviews of apps that collect, and potentially share, children's data are conducted most often by investigators in high-income, predominantly English-speaking countries, and commonly include only apps available in English. Most studies focused on understanding the content of apps designed for specific health or education purposes and few examined game-based and other types of apps children commonly engage with. Surrogate measures are largely used to evaluate the privacy and security features of apps as only a handful of studies have examined app data sharing and security practices directly. Still, our data show that, when data privacy and security evaluations are conducted, issues with frequent data sharing or lax security measures are uncovered.

Data sharing practices

Most researchers included only proxy measures for actual data sharing practices, such as permission requests or the presence of a privacy policy. In the few studies that measured actual data sharing, identifying children's data were provided to third parties.[19] This is problematic as aggregation of these data can support the characterisation of parent and child users according to their app interaction patterns or demographics, and these characterisations may be commercially exploited to encourage impulse purchasing or suggest unhealthy products in ways that exacerbate health inequities.[19 28]

Data sharing policies

Privacy policies in child and parenting apps are variable in terms of both presence and readability. Thus, the data tracking and commercialisation practices of apps, and their associated risks, are generally unknown to children and adults alike[29–31]—challenging the value of the dominant 'notice and consent' privacy framework of the information age. Digital literacy skills-building may mitigate some risks to users and, in the case of children, such programmes have been developed.[29] However, lower socioeconomic status, as well as age and gender, may be associated with lower digital literacy,[31] suggesting that equitable access to literacy training remains elusive. In addition, even when privacy policies are present, they oftentimes do not reflect actual app data sharing behaviours.[32 33]

Table 2 App privacy-related and security-related evaluation methods and results

	Privacy policy		Social media		Permissions requested		Data security	
	Methods	**Results**	**Methods**	**Results**	**Methods**	**Results**	**Methods**	**Results**
Bry *et al*[43]	Evaluated app store page and/or downloaded app manually	*Privacy policy presence:* Less than 5% of apps					Evaluated app store page and/or downloaded app manually	*Login and/or password presence:* Less than 5% of apps
Cheng *et al*[24]							Evaluated app store page and/or downloaded app manually	*Investigator-developed security assessment scale:* 6% of apps rated as excellent; 10% of apps rated as good
Das *et al*[20]	Statistics calculated with web-based readability calculator	*Privacy policy readability:* average reading grade level (12.8) higher than average US adult level (8.0)						
Liu *et al*[22]			Comparison of app library package names with libraries relevant to social networks	*Potential for social medial sharing:* 20% of apps	Examination of privacy grade as listed in online crowdsourced dataset	*Potential for permission requests:* 82% of apps use few permissions for unusual purposes; 10% may use permissions in this way		
Meyer *et al*[23]			Evaluated app store page and/or downloaded app manually	*Social media links:* 14% of apps	Evaluated app store page and/or downloaded app manually	*Permission requests:* 100% of apps Requests for notifications (100%), files/photo storage (53%), phone (13%), microphone (8%), camera (7%); and location (4%).		
Musgrave *et al*[50]							Evaluated app store page and/or downloaded app manually	*Login and/or password presence:* 90% of apps required logins; 70% required passwords
Reyes *et al*[18]							Automated analysis of whether data transmissions are protected	*Data encryption:* 40% of apps do not use TLS*
Robinson *et al*[53]			Evaluated app store page and/or downloaded app manually	*Social media links:* 63% of apps			Evaluated app store page and/or downloaded app manually	*Login and/or password presence:* 0% of apps
Sardi *et al*[21]	Evaluated app store page and/or downloaded app manually	*Privacy policy presence:* 63% of apps *Privacy policy content:* 27% of privacy policies complied with international and federal laws including COPPA†, GDPR‡ and HIPAA§.	Evaluated app store page and/or downloaded app manually	*Social media links:* 31% of apps			Evaluated app store page and/or downloaded app manually	*Login and/or password presence:* 29% of apps *Cloud storage backup option:* 8% of apps

Continued

Table 2 Continued

	Privacy policy		Social media		Permissions requested		Data security	
	Methods	Results	Methods	Results	Methods	Results	Methods	Results
Schoeppe *et al*[54]			Evaluated app store page and/or downloaded app manually	*Social media links:* 60% of apps			Evaluated app store page and/or downloaded app manually	*Login and/or password presence:* 20% of apps
Schoffman *et al*[55]			Evaluated app store page and/or downloaded app manually	*Social media links:* 16% of apps				
Virani *et al*[58]	Evaluated app store page and/or downloaded app manually	*Privacy policy presence:* 100% of apps					Evaluated app store page and/or downloaded app manually	*Login and/or password presence:* 33%–100% of apps
Weber *et al*[59]			Evaluated app store page and/or downloaded app manually	*Social media links:* Less than or equal to 35% of apps			Evaluated app store page and/or downloaded app manually	*Login and/or password presence:* 70% of apps
Zarnowiecki *et al*[63]			Evaluated app store page and/or downloaded app manually	*Social media links:* 25% of apps			Evaluated app store page and/or downloaded app manually	*Login and/or password presence:* 0% of apps

*Transport Layer Security.
†Children's Online Privacy Protection Act.
‡General Data Protection Regulation.
§Health Insurance Portability and Accountability Act.

In-app purchasing and advertisements

Half of our included studies evaluated apps' commercial features with results showing several areas of potential concern. In-app purchase options and advertisements are common, manipulative methods are used to deliver advertisements, and advertising information is potentially harmful to health.[26 34] These issues pose a problem as research shows both parents and children may not always be able to distinguish app content from advertising.[23 35] The content of advertisements within children's apps is also often not age-appropriate with advertisement content

Table 3 App commercial feature evaluation results

Study		Results of commercial feature assessment		
	Total number of apps sampled	% of sampled apps with in-app purchases	% of sample apps with advertisements	Advertisement-related analyses
Biviji *et al*[40]	29	18%	51%	
Brown *et al*[42]	51	43%		
Chen *et al*[44]	22	0%	9%	
Cheng *et al*[24]	47	26%		
Davis *et al*[45]	46		13%	
Furlong *et al*[46]	132	33%		
Liu *et al*[22]	67 778	22%	Potential for advertisements in 53%	
Meyer *et al*[23]	135	46%	95%	Apps included commercial characters (42%), full-app teasers (46%), advertisements that interrupted gameplay (35%), distracting banners (17%) or camouflaged advertisements (7%). Advertisements more prevalent in free apps.
Richardson *et al*[52]	18	6%	17%	
Sardi *et al*[21]	48	32%		
Schoeppe *et al*[54]	25	24%		
Virani *et al*[58]	16	19%	50%	
Wisniewski *et al*[61]	75	24%		
Womack *et al*[62]	48		63%	
Zarnowiecki *et al*[63]	4	50%	25%	
Zhao *et al*[25]	26	46%	85%	Most apps (77%) promoted infant formula
Zhao *et al*[26]	451	95%		Advertisements coded as being related to formula for premature infants, term infants, toddlers and older children including in circumstances where potentially harmful or unnecessary to health

often exceeding developer-stated app maturity levels.[36] Finally, furthering digital disparities, free apps—which parents and children of lower socioeconomic status may more frequently engage with—more frequently contain these in-app purchase options and advertisements.[23]

Implications

Our results have important implications for regulatory bodies, app developers and parents. Although regulations such as the GDPR and COPPA have been enacted to protect children's online privacy, our results point to the limits of these efforts. For instance, COPPA is reported as underenforced in the USA[11] and, as such, non-compliance with the regulation appears widespread.[18 19] These privacy regulations also rely on the idea that an informed consumer can select apps with adequate privacy protections in place.[37] However, we show that privacy policies are not always present in children's apps and, when present, vary greatly in terms of readability. As such, the onus of responsibility for personal data protection is placed on those who may not be adequately equipped for privacy decision making by default (ie, the child or parent). Combined with more stringent regulatory enforcement—app developers, who may not be consistently aware of the destinations of data transmitted from their apps,[18] can reduce personal identifier collection in the spirit of data minimisation[19] and systematically evaluate app privacy behaviours before release.[18] Ahead of these needed regulatory and industry shifts, parents and older children may install apps from trusted developers,[19] disable advertisement identifiers, adjust app permissions and use advertisement blockers to reduce the likelihood of privacy breaches.[38]

Limitations

First, although sensitive, the nature of our research question resulted in a search strategy that was imprecise and identified many irrelevant studies. We used duplicate screening and team discussions to resolve discrepancies and systematically exclude such studies. Second, even though we developed a broad search strategy, the cross-disciplinary nature of our research question may mean that we may not have located all studies accessible in disparate, discipline-focused databases. Third, although not the goal of a scoping review, we did not conduct a methodological quality assessment and instead included all identified studies.

CONCLUSION

Research related to the data handling behaviours and commercial aspects of apps that may transmit children's data is emerging but has not kept pace with the rapid expansion and evolution of the mobile ecosystem. The lack of evaluations may be related to the technical difficulty in doing so—an issue that may be solved by collaborative research efforts spanning the disciples of computer science, child health and commercial regulatory policy. These collaborations may be fruitful in rooting out and acting on risks to children's privacy and well-being within mobile ecosystems.[19] Studies are needed to understand the intersection between transmitted data and advertisements within apps and how this commercial exposure effects children's health and well-being. Ultimately, enforced and stricter regulation may be key to protecting children's online privacy and dampening any impacts of data sharing.

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Appendix 1. Sample Search Strategy (PubMed Search)

Search Query Results

#5 Search: #1 AND #2 AND #3 Filters: from 2005 - 2020

#4 Search: #1 AND #2 AND #3

#3 Search: "Parents"[Mesh] or parent*[tw] OR (pediatric* or paediatric* or child* or newborn* or congenital* or infan* or baby or babies or neonat* or pre-term or preterm* or "premature birth*" or NICU or preschool* or pre-school* or kindergarten* or kindergarden* or "elementary school*" or "nursery school*" or ("day care*" not adult*) or schoolchild* or toddler* or boy or boys or girl* or "middle school*" or pubescen* or juvenile* or teen* or youth* or "high school*" or adolesc* or pre-pubesc* or prepubesc*) OR child*[Journal] or adolesc*[Journal] or pediat*[Journal] or paediat*[Journal] OR "child"[MeSH Terms] OR "infant"[MeSH Terms] OR "child, exceptional"[MeSH Terms] OR "adolescent"[MeSH Terms] OR pediatrics[MeSH Terms] OR "child, abandoned"[MeSH Terms] OR "child, orphaned"[MeSH Terms] OR "child, unwanted"[MeSH Terms] OR "minors"[MeSH Terms] OR ("congenital, hereditary, and neonatal diseases and abnormalities"[MeSH Terms])

#2 Search: "Mobile Applications"[MeSH Terms] OR "Telemedicine"[MeSH Terms] or mhealth[tw] or "mobile health"[tw] or "mobile app"[tw] or "mobile apps"[tw] or "mobile application*"[tw] OR "cellphone app"[tw] or "cellphone apps"[tw] or "cellphone application*"[tw] OR "smartphone app"[tw] or "smartphone apps"[tw] or "smartphone application*"[tw] OR "phone app"[tw] or "phone apps"[tw] or "phone application*"[tw] OR "cellphones app"[tw] or "cellphones apps"[tw] or "cellphones application*"[tw] OR "smartphones app"[tw] or "smartphones apps"[tw] or "smartphones application*"[tw] OR "phones app"[tw] or "phones apps"[tw] or "phones application*"[tw] OR "android app"[tw] or "android apps"[tw] or "android application*"[tw] OR "iOS app"[tw] or "iOS apps*"[tw] or "iOS application*"[tw] OR "health app"[tw] or "health apps"[tw] or "health application*"[tw] OR "tablet app"[tw] or "tablet apps"[tw] or "tablet application*"[tw] OR "tablets app"[tw] or "tablets apps"[tw] or "tablets application*"[tw] OR "software app"[tw] OR "software apps"[tw] OR "software application*"[tw]

#1 Search: "Evaluation Studies as Topic"[MeSH Terms] or "Technology Assessment, Biomedical"[MeSH Terms]) or review*[tw] OR evaulat*[tw] OR assess*[tw] OR feasibility[tw] OR validation[tw] OR effective*[tw]

Appendix 2. Data item charting/abstraction procedure

We charted quantitative and qualitative data on study characteristics (e.g., country of origin, funding source, app stores searched and search date, number of apps included), as well as app user characteristics, app characteristics (e.g., cost, app content), and app data sharing practices, security features, and commercial characteristics. Our abstraction of app data handling and security features focused on passive data sharing practices (i.e., data shared with third parties generally without the knowledge of the user), privacy policy presence and content, active user-initiated data sharing to social media platforms, permission requests, login and/or password presence, data encryption practices, and other identified security feature reports. Our abstraction of the commercial characteristics of apps focused on reports of the presence and type of advertisements and in-app purchases.