Children's acceptance of social robots

A narrative review of the research 2000–2017

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Social robots progressively enter children's lives, but little is known about children's acceptance of social robots and its antecedents. To fill this research gap, this narrative review surveyed 34 articles on child-robot interaction published between 2000 and 2017. We focused on robot, user, and interaction characteristics as potential antecedents of children's intentional and behavioral social robot acceptance. In general, children readily accept robots. However, we found that social, adaptive robot behavior, children's sex and age, as well as frequency of the interaction seem to affect acceptance. Additionally, we found various theoretical and methodological shortcomings in the field. The review concludes with recommendations and directions for future research on children's acceptance of social robots.

Keywords: child-robot interaction, human-robot interaction, human-machine interaction, intention to use, technology acceptance

In recent years, robots have been used increasingly for social purposes (Kahn, Gary, & Shen, 2013). Accordingly, the number of robots for personal use has grown by 22% in 2016 (International Federation of Robotics, 2017). Many scholars agree that *social robots* – that is, robots capable of having a social interaction that approaches interpersonal interaction (Broadbent, 2017) – may assume a prominent role in children's daily life (Beer, Prakash, Mitzner, & Rogers, 2011; Kanda, Hirano, Eaton, & Ishiguro, 2004). In fact, social robots are already used, for example, at schools (Kanda et al., 2004) and in children's home environment (Michaelis & Mutlu, 2017). Against this backdrop, however, a crucial empirical question has rarely been asked: Why do children accept, or reject, social robots in the first place? Without an answer to this question, research on children's interaction with robots lacks a sound base: We need to know first whether children

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accept a social robot at all before we can meaningfully address questions about the character of child-robot interactions and their consequences.

From a theoretical perspective, the acceptance of technology has received considerable scholarly attention, for example, in influential models such as the Technology Acceptance Model (Davis, 1989) and the Unified Theory of Acceptance and Use of Technology (Venkatesh, Morris, Davis, & Davis, 2003). However, acceptance of social robots differs from acceptance of traditional, not primarily social, technologies because social robots are designed to interact with humans (Broadbent, 2017) and may not be perceived or used as a mere tool (Beer et al., 2011; De Graaf & Ben Allouch, 2013; De Graaf, Ben Allouch, & Klamer, 2015; Heerink, Kröse, Evers, & Wielinga, 2010). Moreover, theoretical models and empirical research on social robot acceptance have focused on adult users (De Graaf & Ben Allouch, 2013; De Graaf et al., 2015; De Graaf, Ben Allouch & Van Dijk, 2019; Heerink et al., 2010; Shin & Choo, 2011). Given the substantial developmental differences between adults and children (Belpaeme et al., 2013; Cole, Cole, & Lightfoot, 2005), it is unclear how well these models and empirical findings are applicable to children's acceptance of social robots. Against this backdrop, the goal of this study was to review the child-robot interaction (CRI) literature and to explore the potential antecedents of children's social robot acceptance. As research on CRI comes from different disciplines with different methodological standards, we will also report on methodological characteristics of the studies and how they potentially affect the results. We opted for a narrative review, rather than a meta-analysis, because the field is yet too heterogeneous and scattered for a meta-analysis (Petticrew & Roberts, 2006).

Typically, acceptance of a technology is defined as a repeated, longitudinal use behavior (Davis, 1986; Heerink et al., 2010). It can be seen as the opposite to rejection and encompasses the positive decision to use an innovation (Simon, 2001, p. 87). In this context, De Graaf, Ben Allouch, and Van Dijk (2017a, p. 2) have emphasized that "[o]nly when people are willing to continue to use a technology after initial adoption, one could assume that the acceptance of that technology is a success." De Graaf et al.'s emphasis on people's willingness to continue using a technology is similar to other researchers' focus on people's intention to use a technology. According to these researchers (Davis, 1989; Heerink et al., 2010; Venkatesh et al., 2003), technology acceptance encompasses, next to the actual use of the technology (i.e., behavioral acceptance), the intention to use a given technology (i.e., intentional acceptance) (for an earlier use of this terminology see e.g. Beer et al., 2011). The literature suggests that, conceptually, the acceptance of a particular technology thus requires the continued use of the technology as well as the intention to use it repeatedly (or continue using it). Accordingly, the investigation of CRI necessitates a longitudinal perspective and research design. However, many studies that investigate CRI and robot acceptance only deal with one-time interactions with robots. Even though children's initial acceptance of robots may differ from their acceptance over time (De Graaf, Ben Allouch, & Van Dijk, 2016; Kanda et al., 2004), studies on single interactions between children and robots can be informative for acceptance and will be included in the review, next to studies on repeated child-robot interactions.

Antecedents of robot acceptance

To organize our review, we propose three general categories of candidate antecedents of social robot acceptance: (1) characteristics of the robot, (2) characteristics of the child, and (3) characteristics of the child-robot interaction. The first two categories are derived from Davis' (1989) general model of technology acceptance and the Almere model of robot acceptance (Heerink et al., 2010). In line with research on interpersonal communication, which highlights that interactional features play an important role during communication (for an overview see Burleson, 2010), we focus on characteristics of the interaction as a third category of candidate antecedents. It is important to note that the selection of these candidate antecedents is necessarily limited by the current state-of-the-art and the adult-focus of existing research. Still, we believe that these antecedents can at least guide our narrative review and structure the results.

Characteristics of the robot

In general, people rely on observable cues and behaviors when forming impressions about others (Weibel, Stricker, Wissmath, & Mast, 2010). Accordingly, research has shown that characteristics of the robot predict how people perceive and respond to a robot (Beer et al., 2011; Woods, Dautenhahn, & Schulz, 2004). These characteristics may include physical features, such as a robot's appearance (Minato, Shimada, Ishiguro, & Itakura, 2004; Walters, Syrdal, Dautenhahn, Te Boekhorst, & Koay, 2008) and embodiment (Lee, Jung, Kim, & Kim, 2006; Wainer, Feil-Seifer, Shell, & Mataric, 2006); technical features, such as a robot's degree of autonomy (Heerink et al., 2010; Koay, Syrdal, Walters, & Dautenhahn, 2007); and the robot's behavior, such as social (Heerink, Kröse, Evers, & Wielinga, 2008) and affective behavior (Cameron et al., 2015). The first research question is *whether, and if so which, robot characteristics predict children's acceptance of social robots.*

Characteristics of the user

According to adult technology acceptance models, user characteristics influence the evaluation and acceptance of the technology (De Graaf & Ben Allouch, 2013; Sun & Jeyaraj, 2013). Typical user-characteristics already identified in technology acceptance and human-robot interaction (HRI) are personality (De Graaf et al., 2015; Sun & Jeyaraj, 2013; Walters et al., 2008), education (Heerink, 2011), biological sex (Shibata, Wada, Ikeda, & Sabanovic, 2009), experience with technology (De Graaf et al., 2015; Ezer, 2008; Sun & Jeyaraj, 2013), self-efficacy (Sun & Jeyaraj, 2013), and age (De Graaf et al., 2015). The second research question is *whether, and if so which, user-characteristics predict children's acceptance of social robots.*

Characteristics of the interaction

Two of the essential features of interactions that may influence children's acceptance of social robots are the interaction's duration and frequency (De Graaf, Ben Allouch, & Van Dijk, 2017b; Kanda et al., 2004; Koay et al., 2007). Another characteristic of the interaction that may influence robot acceptance is the robot's role during an interaction, which could vary, for example, from performing a task to interacting with the user (Beer et al., 2011; De Graaf et al., 2015). Moreover, interaction factors, such as the topic of an interaction with a robot as well as the usage context, may play a role in children's acceptance of a robot (De Graaf et al., 2015). The third research question is *whether, and if so which, interaction characteristics predict children's acceptance of social robots.*

Interactions between antecedents

Antecedents of (children's) robot acceptance are likely to also *interact* with one another (Beer et al., 2011; De Graaf et al., 2015). For example, personality characteristics (e.g., personal innovativeness) interacted with frequency of use in explaining acceptance of general technology (Sun & Jeyaraj, 2013): Personality only played a role in the early stages of acceptance, but no longer after frequent use. Similarly, research on HRI found that robot characteristics and user characteristics interacted (Eyssel, Kuchenbrandt, Bobinger, De Ruiter, & Hegel, 2012): Female users accepted a robot with a female voice more readily, whereas male users accepted a robot with a male voice more readily.

In terms of children's acceptance of robots, age and, more specifically, developmental stage may present an important user characteristic that may interact with other antecedents of children's acceptance of social robots. Generally, the child development literature distinguishes between infants (birth to 2 years), young children (2 to 6 years old), old children (6 to 12), and adolescents (12 to 19) (Cole et al., 2005), with each age group being characterized by different developmental stages (Inhelder & Piaget, 1958; Piaget & Inhelder, 2008). Age and developmental stage of children may interact with robot and interaction characteristics due to differences in children's perception of stimuli (Piaget & Inhelder, 2008). Broadly speaking, young children tend to focus on simple perceptual cues, such as appearance, while ignoring complex perceptual cues, such as behavior (Valkenburg & Piotrowski, 2017). For CRI, more specifically, research has shown that children are more likely to attribute human characteristics to robots than adolescents are (Beran, Ramirez-Serrano, Kuzyk, Fior, & Nugent, 2011). The fourth research question is thus *whether antecedents interact with one another – and particularly with children's developmental status – in predicting children's acceptance of social robots.*

Methodological characteristics

Research on CRI is inherently interdisciplinary. The various disciplines that deal with CRI may not only differ in their substantive focus, but also in their methodological approach and standards. We will therefore report on the methodological characteristics of the studies on children's acceptance of social robots. To systematize the results, we distinguish between two groups of methodological characteristics (for a similar approach see e.g. Van Straten, Peter, & Kühne, 2019): general characteristics, which apply to most empirical research, such as study design and sample, and characteristics specifically relevant to research on CRI, such as the degree of robot autonomy.

General methodological characteristics

In terms of general methodological characteristics, we will center on (a) a study's general approach (quantitative or qualitative) and (b) its sampling, sample size, and sample composition. The choice of a quantitative or qualitative approach is related to the extent to which a study's findings can be generalized to populations beyond those studied. In this context, it is crucial for studies to assess how the participants were sampled (e.g., through random, quota, or convenience sampling), how many were sampled, and how the sample was composed. For quantitative studies, we will further assess (c) their design (experimental or correlational) and (d) time frame (longitudinal or cross-sectional). A study's design affects the internal validity of its findings. Finally, it is crucial to know whether a study investigated children's interactions at one point of time only (i.e., cross-sectionally) or at multiple times (i.e., longitudinally). As robots are a novel technology, children typically have high expectations about them and are enthusiastic to interact with them for the first time (Kanda et al., 2004). Consequently, a novelty effect is likely to occur, which includes the first – often enthusiastic – responses of users to a technology, which often do not reflect the patterns of use that will stay over time (e.g., Sung, Christensen, & Grinter, 2009). These initial enthusiastic responses often wear off over time (Fernaeus, Håkansson, Jacobsson, & Ljungblad, 2010; Kanda et al., 2004), and thus the time frame of a study may affect the results of a study.

CRI-specific methodological characteristics

In terms of CRI-specific methodological characteristics, we will review: (a) the control of the robot (autonomous or tele-operated), (b) the setting of the interaction, and (c) the "forced" or voluntary character of the interaction. The way in which a robot is controlled influences its perceived autonomy and, consequently, people's perceptions of the robot (Beer et al., 2011). In addition, the control of the robot and the setting of the interaction affect the study's ecological validity. Finally, it is crucial to assess the "forced" or voluntary character of the interaction, because a "forced"-interaction nature may reduce the ecological validity as well as the variation in quantity and quality of children's robot use. The fifth research question of this study is *whether, and if so which, methodological features affect the outcomes on the antecedents of children's acceptance of social robots.*

Method

As research on children's acceptance of social robots is an interdisciplinary field, multiple databases were searched to select relevant studies: IEEE Xplore, ACM Digital Library (ACM DL), PsycInfo, and Web of Science. We searched the four databases in January 2018 with the search query *(robot* AND child* NOT *surgery NOT operative) AND (accept* OR usage OR evaluat* OR opinion* OR attitude* OR willing* OR perception OR perceived OR reject* OR adopt*).* The terms were chosen to identify records that address children's actual use (i.e., "usage") as well as their intention (i.e., "willingness") to use social robots. We included the other terms because they are often used for, or are strongly related to, acceptance in technology (Davis, 1989; Venkatesh et al., 2003) and social robot acceptance models (Heerink et al., 2010; Shin & Choo, 2011). "Intention to use" was initially used as an additional search term, but did not lead to identification of additional records and was thus excluded.

Whenever possible, we searched the abstract, title, and keywords of articles. As this was not possible for ACM DL, we searched the complete entry and all metadata. Moreover, we only selected articles in scientific journals and conference proceedings, as they are the main source of research in the field of HRI. For ACM DL, we were unable to filter for publication types, and thus selected entries manually. We also confined the search to articles published between 2000 and 2017 as the interactive robots in the 1990's were limited with regard to their responsiveness and ability to process communicative inputs. From the 2000's onwards, social robots have become increasingly better at interacting with others (Mavridis, 2015).

Our initial search elicited 1000 articles. Whenever applicable, we followed the guidelines of the PRISMA approach (Moher et al., 2009). Our approach is similar to that of a systematic literature review (Budgen & Brereton, 2006; Kitchenham, 2004), except for consistently assessing the quality of each study. We excluded 207 articles based on non-topic related criteria (i.e., duplicate, not a journal/proceedings paper, non-English, or no new results) (see Figure 1 for a flow chart of the screening process). In total, 793 articles remained. In a second step, we manually screened the articles to ensure that they were related to children's social robot acceptance. We screened the articles based on the title, abstract, and results section (or the conclusion if no results section was available). If these sections provided insufficient information, the full text was consulted. To warrant the reliability of this selection procedure, a second rater determined for 93 randomly selected articles from the sample whether they should be included or not. There was almost perfect agreement between the two raters, $\kappa = .889$ (97%; $n = 90$). Subsequent discussion led to agreement for the three articles that were initially rated differently.

After this, all 144 remaining articles were fully read. The key selection criterion was whether studies dealt with intentional or behavioral acceptance (as outlined above or in the study itself), or with concepts that are clearly related to any of the two (e.g., rejection). We included studies that focused on the acceptance of specific robot features and studies in which children had to select an interaction partner among robots or among robots and other entities (e.g., humans, animals). Studies were excluded if they exclusively addressed evaluative responses to a robot (e.g., enjoyment, liking). As only a few articles mentioned the concept "acceptance," we also included studies that used measures that correspond in their operationalization to acceptance, but were not conceptualized explicitly as such. The final sample included 34 articles. Most articles dated from 2016 ($n = 13$). The first article on acceptance in this review dated from 2008. To warrant the selection procedure's reliability, a second coder determined for 14 randomly selected remaining articles whether they should be included or not. There was substantial agreement between the two coders, $\kappa = .758$ (93%; $n = 13$). Discussion of the remaining article led to full agreement between the coders.

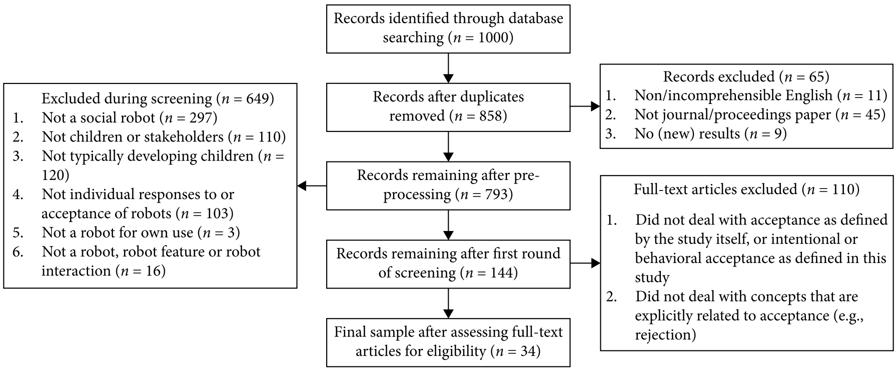

Figure 1. Flow chart of the screening process

Results

The effect of robot characteristics on acceptance

Sixteen articles in the sample analyzed the effect of robot characteristics on children's acceptance of social robots. These can be divided into physical (i.e., appearance and embodiment of the robot), technical (i.e., autonomy), and behavioral characteristics (i.e., social and adaptive behavior of the robot). The studies that investigated the effect of *appearance*, found varying results. One study (Shiomi, Abe, Pei, Ikeda, & Nagai, 2016) found a significant difference in behavioral acceptance for two different human-machine like robots. However, another study that compared a humanoid with a zoomorphic robot showed no effect of appearance on behavioral acceptance (Díaz, Nuño, Saez-Pons, Pardo, & Angulo, 2011). As to *embodiment* of the robot, children's intentional acceptance of a physically embodied robot was equal to that of a virtually embodied one (Kose-Bagci, Ferrari, Dautenhahn, Syrdal, & Nehaniv, 2009). Moreover, when children got the opportunity to play with a physical robot alone or with a physical and virtual robot simultaneously, more children showed behavioral acceptance for the combination of a physical and virtual robot (Fernández-Baena, Boldú, Albo-Canals, & Miralles, 2015).

As for the *autonomy of the robot*, the results were inconclusive. Whereas one study (De Haas, Mois Arayo, Barakova, Haselager, & Smeekens, 2016) did not find a significant difference in children's intentional acceptance of an autonomous and tele-operated robot, another study (Tozadore, Pinto, Romero, & Trovato, 2017) found that children's intentional acceptance of an autonomous robot was higher than that of a tele-operated one.

Five studies analyzed different forms of *social behavior* of a robot. Two of these studies did not find a significant effect of respectively non-verbal (i.e., gazing at the person who was speaking or at the objects talked about) or verbal social behavior (i.e., use of conversational fillers, such as "um") of the robot on children's intentional (Breazeal, Harris, DeSteno, & Kory, 2016) and behavioral acceptance (Wigdor, De Greeff, Looije, & Neerincx, 2016). However, three studies – of which one longitudinal – did find effects of non-verbal (i.e., behaving nicely) and verbal (i.e., praising, encouraging, and showing sympathy, and off-activity talk) social behavior of the robot on intentional (Kanda, Shimada, & Koizumi, 2012; Kruijff-Korbayová et al., 2014) and behavioral acceptance (Díaz et al., 2011).

Finally, six studies investigated the effect of *adaptive behavior* (i.e., adjusting the robot's verbal and/or non-verbal behavior to the child) of a robot on children's acceptance of it. Two studies found no effect of adaptive behavior (i.e., adjusting to the child's mental state or degree of extroversion and emotions respectively) on children's intentional acceptance of the robot (Abe et al., 2012; Looije, Neerincx, & Hindriks, 2017). In contrast, the four remaining studies – of which two were longitudinal – did find an effect of adaptive behavior on children's intentional (Baxter, Ashurst, Read, Kennedy, & Belpaeme, 2017; Blanson Henkemans et al., 2017) and behavioral acceptance of the robot (Sandygulova & O'Hare, 2016; Simmons & Knight, 2017). Children showed a higher acceptance of the adaptive robot compared to the non-adaptive robot. Among these adaptive robot behaviors were motion mimicry (i.e., imitation of the child's motions), adaptation of the robot's sex to the child's sex, and various non-verbal and verbal adaptive behavior (e.g., movement alignment, eliciting emotions dependent on the child's need for relatedness).

Robot characteristics related to the behavior of the robot indeed seemed to play a role in children's acceptance of social robots, whereas few studies consistently studied the effect of physical and technical characteristics of the robot on children's acceptance of it. The effect thus remained inconclusive. Nonetheless, a social, adaptive robot seemed to be more accepted than a non-social, non-adaptive robot.

Finally, it is worth noting that several studies investigated children's acceptance of a particular robot model or compared robots to various media and entities, albeit without addressing the role of antecedents explicitly. In general, children showed intentional (Guneysu & Arnrich, 2017; Hashimoto, Kato, & Kobayashi, 2011; Pulido et al., 2017; Saint-Aimé, Grandgeorge, Le Pévédic, & Duhaut, 2011; Saint-Aimé, Le Pévédic, & Duhaut, 2011) and behavioral acceptance (Wiles et al., 2016) of all social robots. Moreover, children showed the same degree of intentional acceptance towards a robot as to a human (Serholt, Basedow, Barendregt, & Obaid, 2014), an interactive video (Ros et al., 2016), and a tablet (Tozadore, Pinto, Ranieri, Batista, & Romero, 2017). For the tablet, this was also true for behavioral acceptance (Tozadore et al., 2017). However, when given the choice, children who did an activity (i.e., answering questions about health and performing a health exercise) with the tablet were significantly more eager to perform the same activity with the other device, compared to children who did the activity with the robot (Tozadore et al., 2017).

The effect of user characteristics on acceptance

The six articles on the effect of user characteristics on children's acceptance of a social robot can be divided into developmental stage or age of the child, child's sex, and personality. The results on the influence of *developmental stage* and *age* on acceptance were mixed. Whereas two studies found no significant difference for younger and older children in intentional (Leite & Lehman, 2016) and behavioral acceptance (Simmons & Knight, 2017) of the robot, one study found that older children showed higher intentional acceptance of a robot than (pre)adolescents (Al-Taee, Kapoor, Garrett, & Choudhary, 2016). A fourth – qualitative – study (Sabelli & Kanda, 2016) found that "some very young children" (p. 214; 217) did not show behavioral acceptance of the robot. However, the authors did not specify the developmental stage (i.e., infants or younger children) of these children. For the other articles, in which age was not taken into account as an independent variable, we checked for potential effects of children's age or developmental stage on the results (see the supplementary Table for an overview of age ranges per study). However, no clear pattern emerged.

As for a *child's sex*, three studies found no effect on intentional acceptance of a social robot (Al-Taee et al., 2016; Gomes, Sardinha, Segura, Cramer, & Paiva, 2014; Leite & Lehman, 2016), whereas one study did find an effect on behavioral acceptance (Simmons & Knight, 2017): Girls showed a higher behavioral acceptance of the robot than did boys. Finally, one study (Kędzierski, Muszyński, Zoll, Oleksy, & Frontkiewicz, 2013) found positive correlations between various *personality traits* (i.e., openness to experience and agreeableness) and intentional acceptance, as well as between general interest in robots and intentional acceptance.

In sum, when it comes to the effect of user characteristics on acceptance, age or developmental differences between older children and adolescents seemed to influence robot acceptance. However, age or developmental differences between younger and older children did not seem to affect robot acceptance. Whereas a child's sex did not influence intentional acceptance, it seemed to impact behavioral acceptance. Finally, certain personality characteristics seem to affect intentional acceptance.

The effect of interaction characteristics on acceptance

The six studies on the effect of interaction characteristics on children's acceptance of social robots focused on occurrence and frequency, functions and roles of the robot, and conversational violation. Two studies found no effect of the *frequency* or *mere occurrence* of an interaction on children's intentional acceptance of a social robot (Baxter et al., 2017; Ferraz, Câmara, & O'Neill, 2016). In contrast, one study found an effect of the frequency of the interaction on children's behavioral acceptance (Ribi, Yokoyama, & Turner, 2008). Findings of the effects of the *functions* and *roles* of robots were inconclusive. Children had a higher intentional acceptance of certain robot functions (e.g., providing education) compared to others (e.g., companionship) (Al-Taee et al., 2016), but their intentional acceptance was equal across different robot roles (i.e., friend vs. machine) (Westlund, Martinez, Archie, Das, & Breazeal, 2016). A third study (Ros et al., 2016) found no effect of role-switching on intentional robot acceptance. Finally, one study analyzed the effect of *conversational violation* (i.e., the robot bringing up information it could not possibly have) but did not find an effect on intentional acceptance (Leite & Lehman, 2016).

Considering the effect of interaction characteristics on children's social robot acceptance, conversational violation, occurrence, and frequency did not influence intentional robot acceptance. However, the frequency of an interaction affected behavioral acceptance. The effects of the robot's functions and roles on children's acceptance remained unclear.

Interactions between antecedents

One study (Blanson Henkemans et al., 2017) found an interaction effect between *adaptive behavior* of the robot and *frequency of the interaction* on children's behavioral acceptance of the robot. Children who played with the personalized robot played significantly more rounds during the third session compared to children who played with the non-personalized robot, which was not the case during the first and second interaction. Additionally, a *child's sex* interacted with *robot appearance* in their effect on behavioral acceptance (Díaz et al., 2011): When prompted to make a choice, all girls chose the zoomorphic robot, whereas most boys chose the humanoid robot. In another study on behavioral acceptance (Sandygulova & O'Hare, 2016), qualitative observations showed that *child's sex* also interacted with *adaptive robot behavior*: In contrast to girls, some boys rejected a robot that did not adapt its sex to the child's sex. Finally, the effect of *robot role* was found to depend on *children's age*: Certain robot functions had a higher intentional acceptance than others (Al-Taee et al., 2016), but age influenced how the functions were ranked. Compared to children, adolescents had a lower intentional acceptance of a helping role and companionship of the robot. A similar effect emerged for behavioral acceptance: younger children were interested in a robot for storytelling, whereas older children were interested in a robot for interaction and chatting (Banthia et al., 2016).

In sum, when it comes to interactions between antecedents of acceptance, children's age and sex and the robot's adaptive behavior seem to interact with other antecedents of children's acceptance of robots. It is noteworthy that, of the five studies that found these interaction effects, four studied behavioral acceptance as an outcome variable, and one intentional acceptance. Additionally, three of these studies let children interact with the robot freely, whereas the other two used a scripted or "forced" interaction. Whereas to date only the interaction between developmental stage and robot role has been investigated, these findings suggest that children's developmental stage seems to interact with other antecedents.

Methodological characteristics

In terms of their general approach, most studies were quantitative ($n = 30$) (see the supplementary Table for an overview per study). All studies used convenience samples with most studies recruiting through schools ($n = 19$). The samples sizes varied greatly, ranging from two to 120 participants ($M = 36.48$, $Mdn = 27$, $SD = 26.09$). Children's age ranged from one to 16 years, with most studies relying on older children aged six to twelve ($n = 18$). Of the quantitative studies, most chose an experimental design ($n = 20$). Finally, most quantitative studies were cross-sectional ($n = 25$). In terms of the methodological characteristics that are specific to CRI research, autonomously operating robots ($n = 14$) and tele-operated robots ($n = 15$) were used nearly equally often. Most of the studies took place at schools ($n = 13$). Finally, in 27 of the 34 studies, the interaction of the children with the robot was "forced," that is, children were not explicitly presented with a choice when it comes to the duration of the interaction and the interaction often followed a pre-set script.

When looking at the potential effect of methodological features on the results, we focused on the studies that addressed the role of antecedents explicitly, as the other studies differed in their design and comparability was thus difficult. Of these 29 studies (i.e., one article discussed two separate studies) in this sample, ten studies showed effects of certain antecedents on children's acceptance of social robots, seven found mixed results, and twelve did not find any effects. Most studies ($n=6$) that found an effect on robot acceptance, focused on behavioral acceptance as an outcome variable. Additionally, five of these studies on behavioral acceptance let children interact freely with the robot. In contrast, of the studies that did not find any effects of robot acceptance, none of them let children interact freely with a robot, but rather used a "forced" interaction. Only one of these studies focused on behavioral acceptance as an outcome variable, whereas the other all focused on intentional acceptance. Important to note here is that of the full sample, only six articles explicitly mentioned the concept "acceptance" (Al-Taee et al., 2016; Kanda et al., 2012; Looije et al., 2017; Sabelli & Kanda, 2016; Saint-Aimé, Grandgeorge et al., 2011; Shiomi et al., 2016), of which only four (partly) operationalized it as either intentional (Kanda et al., 2012; Looije et al., 2017; Saint-Aimé, Grandgeorge et al., 2011) or behavioral acceptance (Shiomi et al., 2016). The other 28 articles used measures that were (partly) similar in their operationalization to intentional or behavioral acceptance, but were not explicitly conceptualized as such. The exact operationalizations of intentional and behavioral acceptance of each study can be found in the supplementary Table.

Discussion

In this narrative review, we focused on robot, user, and interaction characteristics as antecedents of children's intentional and behavioral acceptance of robots, as well as on methodological characteristics of the studies. We found that social, adaptive robot behavior, children's sex and age, and frequency of a CRI affected children's acceptance of social robots. In addition, if effects occurred, they mostly referred to behavioral acceptance rather than intentional acceptance.

Antecedents of children's social robot acceptance

As to robot characteristics, the finding that a social and adaptive robot was more accepted than a non-social or non-adaptive robot is in line with adult robot acceptance models in which perceived sociability and adaptivity of the robot are indirect predictors of acceptance (Heerink et al., 2010; Shin & Choo, 2011). This finding suggests that robots need to be able to properly respond to their social environment to interact effectively with humans (Belpaeme et al., 2013), which might result in a more natural interaction (Kanda et al., 2004).

As to user characteristics, girls showed a higher behavioral acceptance of robots compared to boys, which is in line with the findings on adults' evaluations of social robots (Shibata et al., 2009). In the other studies reviewed, however, this effect was absent. An explanation may be that the studies that did not find an effect focused on intentional acceptance and used “forced” or scripted child-robot interactions, whereas the study that did find an effect focused on behavioral acceptance and let children interact freely with the robot. It may thus be that the “forced” or “free” character of the interaction as well as the difference between intentional and behavioral acceptance, notably in their measurement, may have caused the different findings. As to the “forced” or “free” character of the interaction, the ecological validity may be limited in studies that employ “forced” or scripted interactions because children typically have the choice to interact freely with robots in their natural environment (e.g., at home or at school). Moreover, the “forced” nature of the interactions limits variations in robot use (e.g., in duration and frequency) across children. Our review demonstrated that most studies were based on such “forced” or scripted interactions between a child and a robot. Interestingly, the studies that allowed children to interact with the robot freely were more likely to find effects on children’s robot acceptance.

The aforementioned different findings may also be related to an inherent methodological difference in the measurement of intentional and behavioral robot acceptance: Intentional robot acceptance is typically measured with self-reports, whereas behavioral acceptance is usually assessed with behavioral measures. Self-report measures may suffer from social desirability biases (Belpaeme et al., 2013; Fisher, 1993) and children may have answered along the lines of what they thought was expected from them, which typically reduces the variance in the answers. Behavioral measures, in contrast, may be less likely to be affected by such a bias. This was reflected in the results: When studies focused on behavioral acceptance rather than intentional acceptance, they often found more variance – and thus significant differences – in children’s acceptance of robots.

Adolescents showed a lower robot acceptance compared to older children. This finding matches earlier results that adolescents do not view robots as social, moral, and animate entities as much as children do (Beran et al., 2011; Kahn, Freier, Severson, & Gill, 2012). Consequently, adolescents are less likely to accept a robot in a social role. Adolescents may also have higher expectations of the robot – not least because of unrealistic depictions of robots in popular science fiction (Dinet & Vivian, 2014; Kriz, Ferro, Damera, & Porter, 2010; Sundar, Waddell, & Jung, 2016) – which may lead to disappointment.

As to interaction characteristics, the frequency of an interaction affected behavioral acceptance but not intentional acceptance. This pattern may be related to the methodological differences in the measurement of the two aspects of acceptance that were mentioned above. An alternative explanation might be that, in the study on intentional acceptance (Baxter et al., 2017), children interacted with a robot only three times, whereas in the study on behavioral acceptance (Ribi et al., 2008) children interacted eleven times with the robot.

Consistent patterns of other robot (i.e., visual characteristics and autonomy) and interaction characteristics (i.e., functions and roles of the robot) on acceptance did not emerge. This may have several reasons. First, cross-sectional studies (i.e., one-time interactions) were much more common than longitudinal studies, which raises an important methodological problem in CRI. Because of the novelty effect (Baxter et al., 2017; Kanda et al., 2004), children may not pay much attention to (experimentally manipulated) characteristics of the robot or interaction (De Haas et al., 2016). Because manipulation checks were typically not provided (for an exception see Leite & Lehman, 2016), it is not clear whether the manipulations were actually strong enough to affect children's responses.

Second, the novelty of the robot may lead to ceiling effects, with children showing a high appreciation of any robot, independent of its specific characteristics (Breazeal et al., 2016; Looije et al., 2017; Nalin et al., 2012). As a result, only minor differences in children's robot acceptance may emerge in single interaction studies, which makes it difficult to identify effects of robot and interaction characteristics. Third, children may, compared to adults, not have fully developed social cognitive competencies to react meaningfully to interaction characteristics, such as robot role, role-switching, and conversational violations (Cole et al., 2005). Children may, for example, yet have to develop their role repertoire to respond adequately to different robot roles or be able to switch roles. Similarly, they may not be able yet to realize when conversational conventions are violated.

Interaction between antecedents

It is noteworthy that the majority of the studies that found interaction effects studied behavioral acceptance, rather than intentional acceptance. Three of these studies additionally let children interact freely with a robot. The finding that children's age interacts with the robot's role is in line with the finding that, as mentioned above, adolescents are less likely to view robots as social entities compared to children (Beran et al., 2011; Kahn et al., 2012), and consequently, may be less likely to accept social robot roles as they get older. Moreover, children at different developmental stages prefer different stimuli (Cole et al., 2005), which might also hold for a robot's role. The different developmental stages of children across the studies may also explain why findings for the effect of a robot's role were conflicting.

The finding that girls preferred a zoomorphic robot over a humanoid robot, whereas for boys the opposite was true, shows that children had gendered play preferences. Typically, boys and girls prefer toys that, stereotypically, fit their own gender to neutral or cross-gender toys (Carter & Levy, 1988; Cherney & London, 2006). Girls, for example, seem to like nurturing play behavior (Miller, 1987), which probably also showed in their preference for zoomorphic, to-be-nurtured robots. The interaction between a child's biological sex and a robot's adaptive behavior meant that boys, rather than girls, were more affected by the lack of adaptive robot behavior. Generally, females tend to be more positive and social in interpersonal interactions and relationships than men (Tobin, Graziano, Vanman, & Tassinary, 2000). Finally, the interaction between adaptive robot behavior and frequency of the interaction also seems related to the novelty effect: Children may have had an initial enthusiasm towards every robot and only started to notice differences after repeated interactions.

The influence of methodological characteristics

Our review of the general methodological characteristics of research on children's acceptance of social robots showed that the studies mostly were quantitative, experimental, and cross-sectional. Samples with relatively small sample sizes (often with only a few cases per condition) dominate the field. This can be problematic as small sample sizes reduce the precision of estimates and the statistical power of inferential tests (Button et al., 2013). Thus, Type-2 errors are likely to occur: One may conclude that there is no significant effect, although sufficiently powered studies may detect a significant effect. Additionally, these small samples were mostly based on convenience sampling. This may cause problems whenever descriptive findings or effect sizes are to be generalized to a larger population. Although the use of convenience sampling is understandable given the demanding requirements of research in this field, future research should look into more representative ways of sampling (e.g., random or quota sampling) whenever generalization of descriptive findings or effect sizes is important.

Our review also pointed to a great diversity in conceptual and operational definitions of robot acceptance. Most of the studies investigated willingness or intention to repeat the interaction with the robot, without referring to it as acceptance. Other studies used the label acceptance, but partly operationalized it differently, for example also referring to ease of use (Looije et al., 2017) or perceived kindness of the robot (Saint-Aimé, Grandgeorge et al., 2011). The diversity of conceptualizations and operationalizations may result from robot acceptance not yet being a key concept in CRI research. Still, the diverse conceptual and operational definitions across studies challenge the validity of the measurements and reduce the comparability across studies. Specifically, and in line with models of adults' robot acceptance and general technology acceptance (Davis, 1989; De Graaf et al., 2019; Heerink et al., 2010; Venkatesh et al., 2003), psychological responses, such as enjoyment of a robot (Shiomi et al., 2016), should not be used as indicators of acceptance but as predictors. Additionally, to fully capture the essence of acceptance, which essentially "[...] is a process that starts with an individual becoming aware of a technology and, ideally, ends with that individual embracing the technology and incorporating its use in his or her everyday life" (De Graaf et al., 2017a, p. 4), it is crucial that studies not only focus on the intention or hypothetical willingness to use a robot, but also on actual usage behavior. Conceptually, this means that we need to move away from the idea of acceptance as a variable toward the notion of acceptance as a process (e.g., Bagozzi, 2007; De Graaf et al., 2017a). Conceptualizing acceptance as a process enables researchers to more clearly distinguish between intention and actual behavior. It is essential to take this distinction into account and study the gap that may exist between intention to use a technology and the actual use of it (see Bagozzi, 2007 for an elaborate discussion of the intention-behavior gap).

Conclusion and future directions

To conclude, our review has shown that research on children's acceptance of social robots is still in its infancy. It is difficult to identify consistent findings about the antecedents of children's acceptance of social robots. Likely reasons for this state of affairs are the novelty of social robots, particularities of child development, and the corresponding challenges of CRI research. The technological and logistical demands of research with social robots are legion (Barco, Van Straten, De Jong, Peter, & Kühne, 2018), and children are a notoriously difficult population to study. Moreover, and in line with what other research has recently identified as issues in research on HRI (Baxter, Kennedy, Senft, Lemaignan, & Belpaeme, 2016; Eyssel, 2017) and CRI (Peter, Kühne, Barco, De Jong, & Van Straten, 2019) in general, our review points to at least three theoretical and five methodological challenges when studying children's acceptance of robots. In terms of theoretical challenges, it is paramount, first, that research on the topic becomes more theory-driven, as currently research is often done ad-hoc, and theoretical frameworks have only begun to emerge (for suggestions see Broadbent, 2017; Eyssel, 2017). Second, we need agreement among researchers on the conceptualization of acceptance, and more specifically on the distinction between intentional and behavioral acceptance, as it is currently unclear whether intentional acceptance should be seen as a predictor of behavioral acceptance or part of the same concept. Third, we need more theoretical and empirical attention to the enormous developmental differences between children and their consequences for the differential acceptance of social robots, as it seems that age affects children's view of a social robot, and consequently their acceptance of it. However, this may only be the case for certain age groups (e.g., children versus adolescents) and depend on the role of the robot.

At least five methodological challenges deserve attention in research on children's acceptance of social robots (for a more general discussion of these challenges in CRI, see Peter et al., 2019). First, in line with what other scholars (Bethel & Murphy, 2010; Eyssel, 2017) have considered a methodological issue in social robotics in general, future studies should replicate existing studies with larger samples to assure statistical power. Second, in order to capture the essence of acceptance, compared to mere use, studies should address repeated use or repeated intention to use in longitudinal studies. Third, CRI studies would benefit from an approach in which the child gets the space to explore the robot and determine the length of the interaction themselves in natural settings. Fourth, we need a more consistent, standardized operationalization of both intentional and behavioral acceptance, which considers the crucial development of acceptance over time. This would also be beneficial for meta-analytic purposes. Fifth and finally, systematic research is needed to address the discrepancy between intentional and behavioral acceptance of social robots.

Despite these challenges, we have identified several patterns of robot, user, and interaction characteristics that seem to influence children's acceptance of social robots. Future research can build on these findings, and investigate the effects of other, potentially important antecedents of children's acceptance of social robots. Moreover, the proposed methodological recommendations will contribute to the identification of more consistent patterns in children's acceptance of social robots. Finally, a better understanding of the antecedents of why children accept robots initially and in the longer run may also improve our grasp of consequences of CRI, for example to what extent children form relationships with robots and trust them.

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Appendix

Author(s), Year Published, Country	Approach	Sampling	Sample size	Age	Design	Nr. of conditions[2]	Time	Control	Setting	Interaction	Independent & dependent variables
Abe et al. (2012), Japan	Quan.	NS	$N=4$	$M=5.5$[1]	Exp.	–	Cross.	Auto.	NS	Forced	*IV*: Adaptive robot behavior *DV*: Does the child want to play with the robot again?
Al-Taee, et al. (2016), UK	Quan.	Clinic waiting areas	$N=37$	6–16	Corr.	Between, $N=3$	Cross.	Auto.	Hospital	Forced	*IV*: Age*, robot's functions* (x)** child's sex *DV*: Acceptability (e.g., as companion, take home, giving advice etc.)
Banthia et al. (2016), Canada	Quan.	(Nursery) school, hospital	NS	3–13	Corr.	–	Cross.	WoZ	University; school; nursery; hospital	Forced	*IV*: Age x** robot role *DV*: Interest in the robot
Baxter et al. (2017), UK	Quan.	School	$N=59$	7–8	Exp.	Between, $N=2$	Long.	Auto.	School	Forced	*IV*: Adaptive robot behavior,* interaction frequency *DV*: "What would you prefer to play next with?"
Breazeal et al. (2016), USA	Quan.	Pre-school	$N=17$	3–5	Exp.	–	Cross.	WoZ	Pre-school	Forced	*IV*: Social contingent behavior *DV*: Desire to play again
De Haas et al. (2016), Netherlands	Quan.	School	$N=20$	7–8	Exp.	Within, $N=2$	Cross.	Auto./Tele-operated	School	Forced	*IV*: Autonomy of the robot *DV*: "I want to play the game again with the robot", "With which robot do you want to play again?"

Appendix *(continued)*

Author(s), Year Published, Country	Approach	Sampling	Sample size	Age	Design	Nr. of conditions[2]	Time	Control	Setting	Interaction	Independent & dependent variables
Díaz et al. (2011), Spain	Quan./ Qual.	School	$N=49$	11–12	Exp.	–	Cross.	Auto.	School	Forced	*IV*: Robot appearance (x)** child's sex, social robot behavior* *DV*: Forced-choice between robots
Fernández-Baena et al. (2015), Spain	Quan.	Summer course	$N=15$	8–12	Corr.	–	Cross.	Auto.	University	Forced	*IV*: Interaction composition* *DV*: "How do you like to play most?"
Ferraz et al. (2016) Portugal	Quan.	After-school program	$N=20$	6–8	Corr.	–	Cross.	Auto.	School	Forced	*IV*: Occurrence of the interaction *DV*: Motivation to play: Repeat the activity
Blanson Henkemans et al. (2017), Netherlands	Quan.	Hospital	$N=27$	7–14	Exp.	Between, $N=3$	Long.	WoZ/ Auto.	Hospital	Free	*IV:* Adaptive robot behavior* (x)** frequency of the interaction *DV:* Playing another time
Gomes et al. (2014), Portugal	Quan.	School	$N=51$	10–11	Corr.	–	Cross.	Auto.	School	Forced	*IV*: Child's sex *DV*: "What would you think of taking *x* home?"
Guneysu et al. (2017), Switzerland	Quan.	NS	$N=19$	$M=8.4$*	Corr.	–	Cross.	Auto.	NS	Forced	*IV: Particular robot model* *DV*: Social attraction
Hashimoto et al. (2011), Japan	Quan.	Schools	$N=38$; $N=22$	6–12; 10–11	Exp.	–	Cross.	WoZ	School	Forced	*IV: Particular robot model* *DV*: "Do you want to participate again?"

Appendix *(continued)*

Author(s), Year Published, Country	Approach	Sampling	Sample size	Age	Design	Nr. of conditions[2]	Time	Control	Setting	Interaction	Independent & dependent variables
Kanda et al. (2012), Japan	Quan.	Schools	$N = 31$	11–12	Exp.	Between, $N = 2$	Long.	WoZ	Lab	Forced	*IV*: Social robot behavior* *DV*: Acceptance: Intention to use *x* in Lego class/other class
Kędzierski et al. (2013), Poland	Quan./Qual	School	$N = 48$	8–12	Corr.	–	Cross.	Auto.	NS	Forced	*IV*: Child's personality & interest in robots* *DV*: Willingness to interact
Kose-Bagci et al. (2009), UK	Quan.	Schools	$N = 66$	9–10	Exp.	Within, $N = 3$	Cross.	Auto.	University	Forced	*IV*: Embodiment of the robot *DV*: Social attraction: "Would like to spend more time/be friends with *x*"
Kruijff-Korbayová et al. (2014), Germany	Quan.	Summer camp	$N = 24$	11–14	Exp.	Between, $N = 2$	Cross.	WoZ/ Auto.	Summer camp	Forced	*IV*: Social robot behavior* *DV*: Interest in another session: Intention to play again & actually booked another session
Leite & Lehman (2016), USA	Quan.	Physical & online bulletin boards	$N = 28$	4–10	Exp.	Between, $N = 2$	Cross.	WoZ	NS	Forced	*IV*: Age, child's sex, conversational violation *DV*: "How much would you like to play with *x* again?"
Looije et al. (2017), Netherlands	Quan.	School	$N = 18$	7–11	Exp.	Within, $N = 2$	Cross.	WoZ	NS	Forced	*IV*: Adaptive, affective robot behavior *DV*: Acceptance: "Would you like to have *x* at home? Did you find it easy to work with *x*? Do you understand x?" Acceptance choice: "Which robot did you find easiest to work with?" Forced choice: "If you had to, which one would you choose?"

Appendix *(continued)*

Author(s), Year Published, Country	Approach	Sampling	Sample size	Age	Design	Nr. of conditions[2]	Time	Control	Setting	Interaction	Independent & dependent variables
Pulido et al. (2017), Spain	Quan.	School	$N=120$	5–9	Corr.	–	Cross.	Auto.	School	Forced	*IV: Particular robot model* *DV*: "Would you like to have *x* at home?"
Ribi et al. (2008), Switzerland	Quan.	Kindergarten & pre-school	$N=14$	3–6	Exp.	–	Long.	Auto.	Pre-school	Free	*IV*: Interaction frequency* *DV*: Refusal to participate
Ros et al. (2016), UK	Quan.	School	$N=84$	9–11	Exp.	Between, $N=4$	Long.	WoZ/Auto.	School	Forced	*IV*: Role-switching, *comparison to video* *DV*: Would like to interact with *x* again
Sabelli & Kanda (2016), USA	Qual.	Shopping mall	NS	NS	Corr.	–	Cross.	WoZ	Shopping mall	Free	*IV*: Age* *DV*: Acceptance: "smiles, joy, running toward it, talking to it, sitting on lap, holding hands"
Saint-Aimé, Grandgeorge et al. (2011), France	Quan.	Nursery schools	$N=13$	3–5	Corr.	–	Cross.	WoZ	School	Forced	*IV: Particular robot model* *DV*: "Do you want to see *x* again/ take *x* home with you?"
Saint-Aimé, Le-Pévédic et al. (2011), France	Quan.	NS	$N=2$	8–9	Corr.	–	Cross.	WoZ	Lab	Forced	*IV: Particular robot model* *DV*: Acceptance: "See again", "keep", "attraction", "touch", "kindness"

Appendix *(continued)*

Author(s), Year Published, Country	Approach	Sampling	Sample size	Age	Design	Nr. of conditions[2]	Time	Control	Setting	Interaction	Independent & dependent variables
Sandygulova & O'Hare (2016), Kazakhstan	Quan.	Play Centre	$N = 74$	3–9	Exp.	Between $N = 2$	Cross.	Auto.	Play Centre	Free	*IV:* Adaptive robot behavior* (x)** child's sex *DV:* Duration of play, rejection behavior
Serholt et al. (2014), Sweden	Quan.	Schools	$N = 27$	11–15	Exp.	Between, $N = 2$	Cross.	WoZ	School	Forced	*IV: Comparison to human* *DV:* Social engagement: "I would like to do another activity with the instructor"
Shiomi et al. (2016), Japan	Quan.	NS	$N = 57$	1–6	Corr.	Between, $N = 3$	Cross.	Tele-operated	Playroom	Free	*IV:* Robot appearance* *DV:* Acceptance: enjoyment/ fun. Rejection: refusal to interact, hesitation, fleeing behavior
Simmons et al. (2017), USA	Quan.	University & community	$N = 45$	5–9	Exp.	Between, $N = 3$	Cross.	Auto.	Lab	Free	*IV:* Adaptive robot behavior *DV:* Number of times returned, duration of interaction
Tozadore et al. (2017), Brazil	Quan.	School	$N = 22$	10–12	Exp.	Between, $N = 2$	Cross.	WoZ	NS	Forced	*IV: Comparison to tablet* *DV:* Interest in having the activity with the other device, perform activity more often, eagerness to end activity, number of stories
Tozadore et al. (2017), Brazil	Quan.	School	$N = 82$	7–11	Exp.	Between, $N = 2$	Cross.	WoZ/ Auto.	School	Forced	*IV:* Autonomy of the robot* *DV:* "Would you like to play without anyone controlling the robot?"

Appendix *(continued)*

Author(s), Year Published, Country	Approach	Sampling	Sample size	Age	Design	Nr. of conditions[2]	Time	Control	Setting	Interaction	Independent & dependent variables
Westlund et al. (2016), USA	Quan.	Municipality	$N=22$	3–7	Exp.	Between, $N=2$	Cross.	WoZ	NS	Forced	*IV:* Robot role *DV:* Play again
Wiles et al. (2016), Australia	Qual.	NS	$N=17$	1–6	Corr.	–	Cross.	WoZ	Science fair	Both	*IV: Particular robot model* *DV:* Interest in the robot: duration & number of games played
Wigdor et al. (2016), Netherlands	Quan.	School	$N=26$	9–11	Exp.	Within, $N=2$	Cross.	WoZ	NS	Forced	*IV:* Social robot behavior *DV:* Free play selection: play with the robot or something different. Photo partner preference.

Note:

1. Range not available
2. Design of the study: within-subjects design or between-subjects design; and number of conditions

* Independent variable showed an effect on dependent variable (not necessarily statistically tested)

** Interaction between the two independent variables on the dependent variable

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