



Social Innovation and Health-Related Well-Being of Left-Behind Children: Evidence from an Intelligent Robot Project in China

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Abstract

In China, rural children, compared to their urban counterparts, are disadvantaged by less parental care and limited access to educational resources. This can have dire consequences for their health-related well-being during a vulnerable and formative stage of the life course. Quality of life (QOL) has been increasingly used as an indicator of individuals' well-being. QOL studies have primarily been conducted in Western contexts, but there is relatively less knowledge on QOL in the Chinese context, particularly for rural left-behind children (LBC). This study analyzed the effects of a socially innovative product – intelligent robots by the Li Ensan Charity Foundation – on the health-related well-being of rural LBC in China. Children who used the robots and reported higher satisfaction with the use experienced positive effects on QOL than their counterparts.. We discussed the implications of these results in the context of micro- and macro-level practice.

Keywords China · Intelligent robots · Health-related child well-being · Left-behind children · Social innovation

Introduction

China has seen a mass internal migration of rural workers to its urbanized seaboard over the past few decades; this migration pattern has been attributed to the allure of higher-paying job opportunities in rapidly growing urban centers. As a result of this internal migration, new subgroups children have formed: migrant and left-behind children (LBC) (e.g. Lu et al., 2016). Migrant children are referred to

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those individuals under 18 years old who have moved from their original place of residence to live in another for 6 months or longer. About 13% of children were migrant children in 2015 in China (National Bureau of Statistics of China, 2017). By contrast, population estimates of LBC varied according to the definition used. National Bureau of Statistics of China (2017) defines LBC more loosely, identifying LBC as those individuals under 18 years old who live in their original place of residence while at least one of their parents have migrated elsewhere to work. China's Ministry of Civil Affairs (MCA) (2016), on the other hand, uses a more restrictive definition: LBC are those *under 16 years old* (a) whose parents have *both migrated* elsewhere to work or (b) who have one migrant parent *and one resident parent that lacks guardianship capability*. Using definitions from the MCA and the Bureau of Statistics of China as low- and high-bound estimates, respectively, the Chinese LBC population in 2015 ranged from 9 to 69 million children.

Past literature has found that rural children have inferior development and well-being than their urban counterparts (Liu et al., 2013; Wang & Mesman, 2015). Rural children, especially LBC, tend to have poor physical health (e.g. Lei et al., 2018); experience more psychological and behavioral problems (e.g. Ling et al., 2015); and display poor social and educational outcomes (e.g. Lu et al., 2016).

The rise of left-behind and migrant children can be traced to the beginnings of *hukou*, a national identification and classification system established by a 1958 household registration policy. In an effort to limit internal migration, the Chinese government implemented this system to divide the national population into two classes, urban and peasant (i.e., rural); these classes determine residency and, ultimately, eligibility for social welfare (Chan, 2010; Chan & Buckingham, 2008). As a result of the system, members of the rural class who migrate to urban centers cannot establish urban residency, making them ineligible for social welfare and educational benefits in cities (Chan, 2010; Chan & Buckingham, 2008). For migrant children living in cities, this means that educational opportunities are few and far between. Urban schools often deny admission for children with rural hukou, and those that do admit rural children typically charge their parents an extra fee. To avoid this extraneous financial burden, many parents choose to migrate to cities without their children (Ye & Pan, 2011), leading to the many challenges that come with long-term parent-child separation (Zhou et al., 2014).

Recently, the Li Ensan Charity Foundation launched a social innovation project applying intelligent robots to foster the well-being of LBC. The present study aims to investigate this initiative's effects on rural LBC's health-related well-being. Our paper begins with a literature review on the health-related well-being of LBC, followed by a brief introduction to Li Ensan Charity Foundation's product. We then present our data, measures, and analytic approach in the methodology section, followed by a discussion of the findings, significance, and implications for existing interventions used to improve health-related child well-being. The article concludes with potential directions for future research.

Health-Related Well-Being of Left-Behind Children

Physical and Emotional Functioning

Rural LBC have poorer physical health and functioning than their urban counterparts (e.g. Lei et al., 2018;). Based on data from the China Health and Nutrition Survey (CHNS), Liu et al. (2013) studied the effects of socioeconomic status on health outcomes of rural children. The dataset, collected between 1989 and 2006, contained approximately 15,700 children, including 3,700 urban children and 12,000 rural children. They found rural children were less likely to reach age-appropriate height and weight. Another study found that LBC tend to have unhealthy diets and poor nutrition. In addition, female LBC consumed higher amounts of sugar (Gao et al., 2010). These health conditions may be attributed to inadequate guardianship and parental care. Analyzing the data from rural school-aged children and their caregivers (N = 519), Zhou et al., (2020a, b, c) found that parental presence was positively correlated with children's health status. In other words, parental absence due to labor migration has a negative correlation with child health.

Rural LBC also experience lower emotional functioning than their urban peers (Jia & Tian, 2010; Lu et al., 2016). Xu et al. (2018) studied long-term parent-child separation and its relation with psychological adjustment of LBC. Of the over 500 rural children sampled, over 80% had experienced long-term separation from their parents. Duration was associated with poorer psychological adjustment. The results of Hu et al.'s (2014) study suggest that rural LBC experienced more emotional symptoms than their peers. In Jia and Tian's (2010) cross-sectional study on risk factors of loneliness experienced by LBC, LBC living under the guardianship and care of grandparents had loneliness scores 2.3 points greater than LBC who were living under parental guardianship. Loneliness scores were also negatively associated with the extent of communication between parents and children.

Importantly, while many studies indicate that LBC do have worse adjustment, there is ample literature to suggest that LBC do not *inherently* experience poorer physical and emotional functioning (e.g. Li et al., 2019). In one study, there were no differences in physical health between school-aged LBC and non-LBC (Jia et al., 2010 [N = 640]). Scholars must be careful to avoid reductive language that may overgeneralize LBC and their experiences. Instead, we must consider that there are many other factors that contribute to rural LBC's well-being. In fact, Cheng and Sun's (2014) systematic review of the literature on mental health among LBC underscores that most studies do not control for related risks and events, making it a challenge to clearly ascribe the root of the problems was being left behind rather than other confounding variables. For example, He et al. (2012) examined depression risk of LBC in relation to social support. Those who reported low levels of social support had greater likelihood of depression risk (OR = 5.56), but those with higher degrees of social support had less depression risk (OR = 0.50). In all, LBC can demonstrate extraordinary resilience. Hu (2019)

found that the way that adolescent LBC interpret parental migration is a significant contributing factor to their resilience. In this study, LBC who had a positive perception of their parents' rationale for labor migration demonstrated higher resilience.

Social and School Functioning

LBC, relative to urban children, display lower social and school functioning (e.g. Jiang et al., 2015). Past findings have indicated that rural children tend to engage in risky behaviors and less to have pro-social behaviors (Gao et al., 2010; Hu et al., 2014). Huang and colleagues (2015) found that LBC scored, on average, 5 points lower than non-LBC on social functioning (N = 1400). LBC also have fewer years of schooling and worse academic performance (e.g. Lu et al., 2016). As with physical and emotional functioning, however, it is important to consider confounding variables that may contribute to lower social and academic functioning; peer victimization, for example, is prevalent among LBC (Tang et al., 2018) and can lead to academic difficulties (Schwartz et al., 2005).

Educational and Parental Resources

Limitations in educational and parental resources have contributed to many of the observed disparities between rural and urban children (Gao et al., 2010; Lei et al., 2018;). Hu et al. (2014) found that differences in behavioral and psychological outcomes between urban and rural children are smaller after taking account of educational and parental resources. Huang et al. (2015) found LBC had poorer functioning than non-LBC in physical, emotional, social, and school dimensions. Regression findings revealed that overall functioning was positively associated with mothers' level of education; by contrast, extended maternal absence and less frequent parental visitation were negatively associated with LBC's functioning.

Availability of educational resources has been shown to have significant effects on these achievements (Chetty et al., 2014; Darling-Hammond, 2000; Lafortune et al., 2018). Rural LBC are disadvantaged by limited funding, low-quality educational facilities, less qualified instructors, and higher student-to-teacher ratios (Hu, 2008; Zhang et al., 2015).

Additionally, insufficient parental care has been shown to contribute to lower likelihood of food security among LBC when compared to other rural children. In fact, LBC have lower daily food intake than rural non-LBC (Luo et al., 2008). This resulted in significantly worse health outcomes in LBC, evidenced by lower hemoglobin levels and greater prevalence of anemia (Luo et al., 2008). Many children are left in the guardianship of their grandparents, but often elderly caregivers struggle to provide adequate care and attention. Grandparent caregivers, who may have to contend with their own health concerns, must maintain the household and engage in strenuous agricultural labor while also caring for their grandchildren. Lu et al. (2018) found that LBC, compared to urban, rural, and migrant children, received the least amount of restrictions on time allocated to watching television.

Overall, LBC have been indicated to have poorer well-being compared to urban children and even other rural children. Current literature has shown that this difference is likely to be related to the quality of educational and parental resources. However, a considerable portion of studies about QOL is based on Western, industrialized, and democratic societies (Nielsen et al., 2017), and studies in non-Western contexts exist in fewer numbers (Leung & Fung, 2021; Shek, 2014; Shek, 2020; Shek & Lin, 2017). This study serves to fill this literature gap on quality of life in an impoverished region of a non-Western country.

Social Innovation for Left-Behind Children

Social innovation is the invention of new services and activities for the purpose of solving social problems or meeting social needs. It offers ground-breaking solutions for persistent social problems within the community (Mulgan et al., 2007). Social and business innovations differ in their contrasting motivations: while the latter aims to maximize profits, the former seeks to fulfill a social need (Donner & Huang, 2017). Mulgan et al. (2007) narrow the definition of social innovation by also requiring new programs or organizations to be replicable.

Overall, social innovation is distinguished by two qualities: newness and purpose. It requires intentional actions, involving the planning and coordination of a novel solution, to meet a specific goal that creates social change (Cajaiba-Santana, 2014). For example, a social innovation may provide groundbreaking solutions to social problems like inequality, barriers to medical services, and food insecurity (Cajaiba-Santana, 2014; Mulgan et al., 2007). In recent years, such solutions have been the products of multidisciplinary teams comprised of individuals working in private business, the government, and non-profit agencies.

Technological advancements continuously expand the limitations of human living. For example, the arrival of artificial intelligence (AI) has inspired the production of robots designed to assist people with day-to-day living, improving their quality of life. Intuition Robotics created robots that implement cognitive processing and communication technologies; these robots can provide health reminders, share news and weather, have interactive conversations, as well as provide emotional support to users (Intuition Robotics, 2021). The field of medicine has also made use of robotics to perform surgeries more effectively (Schurr et al., 2000). The ARTEMIS device, for example, has been used to operate on patients in a minimally invasive manner, reducing risk during operations and recovery time afterwards (Lanfranco et al., 2004).

Intelligent robots, as an attractive tool of social innovation, have shown promise in surpassing current limitations in the study of child well-being. More specifically, intelligent robots offer new ways of promoting health-related functioning. Robots have been studied as a vehicle to deliver therapy to children diagnosed with autism spectrum disorder (ASD) (Diehl et al., 2012). Scholars posit that robots may promote children's social capacity by providing more predictable and simpler social interactions and teaching social skills (Broadbent, 2017). Some empirical evidence supports this speculation. For instance, Kozima et al. (2005) found that

the interactive robot *Keepon* effectively induced mood relaxation among children with ASD. Intelligent robots have educational merit as well; such technology has been applied in the teaching of technical skills and providing peer encouragement (Mubin et al., 2013). Finally, in China, Xie et al. (2019) found that use of the intelligent robots increased child development outcomes. By contrast, the use of other electronics (e.g., watching television) had a negative effect on the outcomes. At the same time, the wide prevalence of internet coverage creates a vehicle by which to advance parent–child communication and parental care during long-term separation (Xie et al., 2019).

The promising effects of the intelligent robots on LBC can be explained by the concept of social capital. Social capital refers to social resources found in relationships; these resources facilitate individuals' ability to produce desired social outcomes and achievement (Coleman, 1990). The physical presence of parents and parental attention towards children are conceptualized as family social capital (Morrow, 1999). In other words, family social capital is composed of various family and parenting processes, which ultimately affect child development (e.g. Leung & Shek, 2019). For LBC, parental absence results in reduced family social capital, subsequently impairing their development and well-being. It also should be noted that positive youth development (PYD) stresses the reduction of problem behaviors and highlights healthy development (Lerner, 2004, 2018; Qi et al., 2020). Thus, intelligent robots could work as a tool that both remedies reduced family social capital and promotes the positive development of the LBC.

This study seeks to investigate whether the use of Intelligent Robots, developed by the Li Ensan Charity Foundation, is associated with the health-related well-being of LBC in China. Considering the aforementioned merits of intelligent robots, we hypothesize that intelligent robots can benefit LBC by improving their functioning and promoting their health-related well-being. Given this, AI robots appear to be a strong candidate for a pioneering solution to the social issue of sparse educational resources in China's rural and impoverished regions.

Methods

Data and Sample

The data of this study were from a face-to-face interviews conducted with 1st and 2nd grade students at three rural elementary schools in Hunan and Sichuan of China.. These schools were selected by Li Ensan Charity Foundation because of their poor socioeconomic indicators, evidenced by substandard infrastructure and education resources, and a high ratio of LBC. Considering the child developmental stage and the appropriateness of robot skills, this project targeted students in 1st and 2nd grades. Each school's review board approved of the study to be conducted at their facility, and participation was voluntary. Distribution excluded three students due to individual personal and health reasons. All other 1st and 2nd grade students received their own robots.

Procedure

Students who received the robots had full access to the functions of the robots between June 2017 and March 2018. The robots were equipped with five basic capabilities – Chinese poetry recitation, storytelling, singing, private conversation, and online communication with parents. The capabilities of Chinese poetry recitation and storytelling were classified as “educational functions” to improve school and social functioning. Meanwhile, the remaining capabilities targeted emotional and physical functioning. Singing and private conversation were classified as “self-care functions.” The last function, online communication with parents, was classified as a “parental care function:” parents could communicate with their child by connecting to the projects’ database using personal cellular devices (Li Ensan Charity Foundation, n.d.). The research team provided various in-person activities/services every month to promote proper usage and ideal outcomes. For instance, the research team hosted monthly sessions to inform the most recent updates on the robots’ functions and provide instructions on product use. Moreover, the research team provided one in-home visit every month to understand students’ use of robots and collect feedback for future improvements. Students’ conversations were backed up on the platform. When students disclosed potential suicidal or other risky thoughts, the research team would have professionals provide counseling.

One hundred and seventeen (117) left-behind students were interviewed between March and June of 2018. Eleven students were missing information on key variables and were therefore excluded from our final analytic sample. As a result, our final sample size contained 106 students. Four students were put on a waiting list to receive robots due to shortage. Because these children had similar demographic characteristics to the children of this study, they served as a good reference group in our analysis. It is worthy to note, however, that future research with a larger reference group could produce stronger and more accurate estimates of treatment effects.

Measures

In this study, we measured the dependent variable, health-related child well-being, with the child report of Pediatric Quality of Life Inventory (PedsQL), which has been shown high validity and reliability for the measurement of health-related quality of life (HRQOL) (Chan et al., 2005; Huang et al., 2015; Varni et al., 2007). PedsQL utilizes 23 items to assess physical, emotional, social, and school functioning. Examples of PedsQL items include “It is hard for me to do sports activity or exercise” and “I have trouble getting along with other kids”. Respondents reported the frequency at which they experienced these occurrences in their daily lives. Responses ranged from “4” for “almost always” to “0” for “never.” We followed the PedsQL coding scheme and coded “0” as “100,” “1” as “75,” “2” as “50,” “3” as “25,” and “4” as “0.” We used average scores as the measure of child well-being. Higher scores represents greater child well-being. The Cronbach alpha of PedsQL was 0.81 in this study.

The main independent variable of the current study was the use of the Intelligent Robots. We assessed usage in two ways. The first was a dichotomous variable, whether or not the robot was used. The second way we measured usage was by the duration of daily use, in hours. We first examined the hours of use as a continuous variable. Then, we constructed this variable to a categorical level (no use; less than 1 h; 1–2 h; and more than 2 h per day). We further measured usage by examining the use and satisfaction of each of the five robot functions. The satisfaction of each function ranged from 1, “very dissatisfied,” to 5, “very satisfied.”

Our model controlled for child, parent, and family characteristics. The specific child characteristics that we controlled for were *age*, *gender*, *grade*, and *electronic use*. Based on previous findings of the negative effects of *electronic device* on child well-being (Heft & Swaminathan, 2002; Maher et al., 2012), students were asked to report how much time do they spend with cell phones, computers, TV, handheld video games, and other electronic devices other than schoolwork on a usual day. We controlled for a variety of parent and family characteristics by inquiring about *parental marital status*, *caretaker identity*, *caretaker health status*, and *family location*. *Parent marital status* was a 5-level categorical variable with the following values: married, divorced, separated, widowed, and unknown. *Unknown* was selected if a child was unable to report on their parents’ marital status. *Caretaker identity* was also a categorical variable and could take on the four values of mother, father, grandparent, and others. The health status of the caretaker was included as a control in our analysis. This decision was informed by past literature that has identified caretaker health as an important influencing factor of child outcomes (Raina et al., 2005). Health status could be categorized as “good,” “fair,” or “poor.” “Good” revealed that the child’s caretaker did not have any physical ailment and was capable of living independently. “Fair” indicated that the caretaker lived with some disease but could continue to maintain independent living and work. Finally, a caretaker with “poor” health was one who was unable to sustain some form of labor but lived independently. Lastly, family location was a dichotomous variable indicating the province, either Sichuan or Hunan, that the family resided in.

Analytic Strategy

Descriptive analysis was first conducted to assess the sample characteristics. It was followed by the ordinary least squares (OLS) regression to gauge the effect of the independent variable on the dependent variable, health-related child well-being. This analysis controlled for all other variables, including child, parent, and family characteristics. For our set of models, we first run the regression on overall PedsQL score, followed by individual PedsQL subscale. Finally, as a test of robustness, we regressed PedsQL scores and subscale scores on use and satisfaction with the various robot functions.

Results

Descriptive Findings

The descriptive results of the sample were displayed in Table 1. Children, on average, were at 7.3 years old. Over half (54%) of the children were female. Over half (55.7%) were in second grade. 62% of the children reported that their parents were married, followed by divorced (13.2%), separated (8.5%), and widowed (4.7%). About 11% of the sample could not report on their parents' marital status because they did not know. The majority of the sample (93.4%) reported that they were being taken care of by their grandparents. A majority of caretakers were reported to be in good health (54%), followed by fair (32%) and poor (14%) health.

The sample's average health-related well-being score was 80.8 ($SD = 12.5$). Varni and colleagues have found that PedsQL scores below 68.7 could be indicated at-risk well-being. The finding suggested that overall, the children included in this study had satisfactory health-related well-being, but some had poor health-related well-being. According to at-risk scores for each functioning (Varni et al., 2003), the sample scored lower on physical and emotional functioning but higher on social and school functioning. A majority (96.2%) of the sample used the Robots. The children used the robots for 1.3 h daily ($SD = 0.7$). About three-quarters, or 74%, of the sample used the robots for less than 1 h.

Table 2 presents the degrees of use and satisfaction with the various functions offered by the Intelligent Robots. Overall, children used all functions, except parent communication, frequently. A range of 93% to 100% of the children reported using each of the functions. By contrast, 71% reported using the parent communication function. Children reported high satisfaction with singing, storytelling, and reciting poetry; scores for parent communication and private conversation were low with large variance.

Regression Results

The OLS regression estimates of the PedsQL score were listed in Table 3. Three different models were presented. Model 1 treated the use of the robots as a dichotomous variable (yes or no). Model 2 assessed the linear effect of robot usage in hour unit. Model 3 examined the robot usage in a 4-level categorical variable (no use; less than 1 h; 1–2 h; and 2 h and more). For this model, the reference group was “no use.”

In our first model, any use of the Intelligent Robots had strong effects on PedsQL scores. After taking account of all other variables, children who did use robots had health-related well-being scores that were 20.43 points higher than their counterparts. In this model, 3 control variables appeared to significantly affect dependent variable. Children whose caretakers were in poor health, as opposed to good health, scored 8 points lower on their health-related well-being scores. Furthermore, male children's PedsQL scores were 4 points lower than those of females. Children whose

Table 1 Mean and Standard Deviation of Key Variables (N = 106)

	Mean (S.D.)
PedsQL [0–100]	80.8 (12.5)
Physical Functioning [0–100]	77.2 (16.2)
Emotional Functioning [0–100]	79.3 (17.4)
Social Functioning [0–100]	86.6 (16.7)
School Functioning [0–100]	82.0 (15.9)
Robot Use [%]	
No	3.8
Yes	96.2
Hours on Robot Use	1.3 (0.7)
No [%]	3.8
< 1 Hour [%]	73.6
1–2 h [%]	12.3
2 h and more [%]	10.4
Age	7.3 (0.7)
Gender [%]	
Male	46.2
Female	53.8
Grade [%]	
First	44.3
Second	55.7
Hours on Electronic Use	1.3 (0.7)
Parent Marital Status [%]	
Married	62.3
Separated	8.5
Divorced	13.2
Widowed	4.7
Unknown	11.3
Caretaker [%]	
Grandparent	93.4
Others	6.6
Caretaker Health [%]	
Good	53.8
Fair	32.1
Poor	14.1
Location [%]	
Sichuan	54.7
Hunan	45.3
N	106

families lived in Hunan had scores that were 9.4 points higher than those from Sichuan. Finally, time spent using other electronics and parents' marital status were both found to have marginally significant effects on child health-related well-being.

Table 2 Usage and Satisfaction of the Robots

	Mean (S.D.)
Usage of Functions [%]	
Parent Communication	70.6
Singing	100
Storytelling	97.1
Reciting Poems	93.1
Private Conversation	93.1
Satisfaction of Functions [1–5]	
Parent Communication	4.1 (1.0)
Singing	4.7 (0.8)
Storytelling	4.6 (0.9)
Reciting Poems	4.6 (0.8)
Private Conversation	4.3 (1.1)
N	102

Table 3 Regression Estimates of Health-Related Well-Being

Model	1			2			3		
	B	S. E	P	B	S. E	P	B	S. E	P
Robot Use	20.43	6.57	**	—	—	—	—	—	—
Hours on Robot Use	—	—	—	4.57	1.60	**	—	—	—
No	—	—	—	—	—	—	—	—	—
< 1 Hour	—	—	—	—	—	—	18.30	6.64	**
1–2 h	—	—	—	—	—	—	22.35	7.16	**
2 h and more	—	—	—	—	—	—	23.99	7.11	**
Hours on Other Electronic Use	-3.30	1.72	+	-3.08	1.73	+	-3.35	1.72	+
Age	-1.17	1.67	—	-1.71	2.09	—	-1.29	2.07	—
Boy	-3.94	1.89	*	-4.10	2.28	+	-4.07	2.25	+
2 nd Grade	1.71	2.55	—	3.56	3.05	—	2.15	3.07	—
Separated	-8.18	3.75	+	-6.89	4.05	+	-7.37	4.04	+
Divorced	-5.39	3.33	—	-3.03	3.49	—	-4.08	3.48	—
Widowed	-6.77	5.07	—	-11.21	5.50	*	-6.67	5.83	—
Marital Unknown	2.84	3.08	—	5.85	3.79	—	4.17	3.82	—
Caretaker, Grandparent	4.05	4.51	—	4.03	4.55	—	3.84	4.52	—
Caretaker, Health, fair	-4.48	2.49	+	-4.23	2.51	+	-4.38	2.52	+
Caretaker, Health, poor	-7.97	3.54	*	-8.54	3.55	*	-7.77	3.56	*
Location, Hunan	9.39	2.74	**	7.82	2.76	**	8.65	2.75	**
Constant	70.59	16.24	***	87.26	14.91	***	72.39	16.23	***
Adjusted R-square	0.22			0.20			0.23		
N		106							

Note: N = 106. + p < .10, * p < .05, ** p < .01, *** p < .001

For each 1-h increase in other electronic usage, the PedsQL score decreased by 3.3 points. Children with separated parents had PedsQL scores that were 8.18 lower than those of children with married parents..

Models 2 and 3 also provided strong evidence of the robots' positive effects on health-related child well-being. In model 2, each 1-h increase of robot use was related to a 4.6-point increase in the PedsQL score. Based on results from model 3, those who spent less than 1 h using the robots had an increase of 18.3 points on their PedsQL scores compared to children who did not use the robots at all. The PedsQL scores of those children who spent 1–2 h increased by 22.4 points, and those who spent 2 or more hours had PedsQL scores 24.0 points higher. Estimated coefficients of all other variables appeared similar to those in model 1, with some differences. For example, children who reported that their caretakers were in fair or poor health had lower PedQL scores than children whose caretakers were in good health.

Table 4 lists the findings of regressing PedsQL subscale scores on robot usage. The models followed the formation of model 2 in Table 3. We listed only the results of key variables for simplicity. Hours of robot usage had robust and large effects on health-related child well-being. Usage was positively associated with physical functioning and marginally positively associated with social and school functioning. Emotional functioning was not affected by robot use. Notably, time spent using other electronic devices appeared to have negative influences on physical functioning.

Table 5 shows the OLS estimates for when PedsQL and subscale scores were regressed on robot function use and satisfaction. For our analyses on function usage, our analytic sample was limited to 102 cases. Table 5 lists five specifications that contained all variables utilized in Model 2 from Table 3. The use of and satisfaction with private conversation, singing, and storytelling all showed solid effects on the overall PedsQL scores and subscale scores. Students who used the private conversation function had 12.0 points greater PedsQL scores than those who did not use the function. When examining the subscales, we found that engaging with the robot's private conversation feature increased physical functioning by 12.5 points and social functioning by 20.5 points. Satisfaction with the private conversation feature was related to an increase of 3.0 points on overall PedsQL scores. In particular,

Table 4 Regression Estimates of PedsQL Subscales

	Physical Functioning			Emotional Functioning			Social Functioning			School Functioning		
	B	S. E	P	B	S. E	P	B	S. E	P	B	S. E	P
Hours on Robot Use	6.14	2.20	**	2.89	2.24		4.18	2.34	+	4.13	2.11	+
Hours on Other Electronic Use	-5.63	2.38	*	-2.66	2.42		-1.07	2.53		-1.42	2.28	
N	106											

Note: * $p < .05$, ** $p < .01$, *** $p < .001$

Table 5 Regression Estimates of PedsQL by Robot Functions

	PedsQL			Physical Functioning			Emotional Functioning			Social Functioning			School Functioning			
	B	S.E	P	B	S.E	P	B	S.E	P	B	S.E	P	B	S.E	P	
Specification 1																
Parent Communication Use	-1.10	3.08		-2.19	4.04		-3.22	4.42		3.18	4.58		-1.51	3.93		
Parent Communication Satisfaction	0.60	1.28		1.70	1.68		-0.25	1.84		-0.52	1.91		0.79	1.64		
Specification 2																
Singing Use	--	--		--	--		--	--		--	--		--	--		
Singing Satisfaction	2.63	1.51	+	2.65	2.01		0.91	2.21		3.26	2.26		3.68	1.93	+	
Specification 3																
Storytelling Use	17.87	6.45	**	16.48	8.64	+	23.23	9.39	*	19.58	9.81	*	13.01	8.45		
Storytelling Satisfaction	1.05	1.27		2.47	1.70		0.51	1.85		-1.44	1.93		1.79	1.67		
Specification 4																
Reciting Poems Use	4.75	4.72		2.33	6.26		2.19	6.89		5.74	7.28		8.90	6.02		
Reciting Poems Satisfaction	1.54	1.55		2.54	2.06		2.55	2.17		-0.03	2.39		1.29	1.97		
Specification 5																
Private Conversation Use	12.03	4.35	**	12.51	5.87	*	6.85	6.64		20.50	6.60	**	7.97	5.76		
Private Conversation Satisfaction	2.44	0.99	*	3.09	1.35	*	2.06	1.52		1.26	1.51		2.96	1.32	*	
N	102															

Note: * p < .05, ** p < .01, *** p < .001

satisfaction with this feature was related to a 3.1-point increase in physical functioning and a 3.0-point increase in school functioning. Using the storytelling feature was related to a PedsQL score of 17.9 points higher. In the context of the subscales, using the storytelling feature was associated with increases in physical functioning by 16.5 points, emotional functioning by 23.2 points, and social functioning by 19.6 points. Children's reported satisfaction with the singing function was marginally related to a 2.6-point greater difference in the PedsQL score and a 3.7-point greater school functioning score.

Discussion

Using PedsQL scores as a metric for health-related well-being, our findings indicate that rural LBC generally have fair health-related well-being; however, upon further investigation, LBC scored lower on the PedsQL subscales of physical and emotional functioning. Engagement with the robots' different functions was showed to be related to improved physical functioning, suggesting the strong potential of this innovative application of AI technology in child development.

A majority of the children who were issued robots used them daily at an average of 1.3 h per day. Four of five functions were used at a high rate; over 90% of the sample reported that they used the singing, storytelling, poem recitation, and private conversation functions. Parent communication was used at an unexpectedly lower rate: 70.6%. It was discovered that weak or unavailable internet connection in rural areas lowered the utility of this particular function. This suggests an underlying reason for the lower satisfaction ratings for both private conversation and parent communication, functions that required a strong internet connection to work properly. Moving forward, however, this provides a clear direction for the future of Xiao En Intelligent Robots.

In line with past literature, our results indicate that a longer duration of use of other electronics showed strong harmful effects on child well-being. On the other hand, children who were satisfied with the robots, implying that they used the robots, had higher PedsQL scores. This finding suggests that not all electronic usage is negatively associated with child well-being. Instead, we can potentially foster and promote child quality of life by replacing negative electronic usage with educational devices, like the intelligent robots used in this study. Our results show that such devices can advance child well-being across physical, school, and social functioning. Satisfaction with robot capabilities (i.e., private conversation, storytelling, and singing) was positively correlated with higher scores in the subscales that measured physical, social, and school functioning. The remaining capabilities of parent communication and poem recitation appeared to have no significant effect on PedsQL scores. Thus, it is important to tailor the product's capabilities to be reflective of users' needs and interests to better attract engagement and satisfaction. For example, the parent communication function did not perform as intended. Further investigation revealed that the messages sent by parents or children often

went unreceived by their intended recipient, a result of poor internet connection or parents' unavailability.

Past literature has implicated that prolonged parental absence can have a major negative impact on child well-being. As such, the Intelligent Robots project sought to improve upon the parent communication function to effectively narrow the distance between parents and their LBC; the parent communication function was intended to fulfill this purpose. The promise of intelligent robots does not necessarily overshadow the potentially negative effects of their use. Although the robots were not negatively associated with the LBC's health-related well-being, these results do not necessarily indicate that the robots do not have any negative effects. Excessive use of robots could distract children from their academics, and the lack of close supervision by a parent or guardian could exacerbate the problem. Future implementation should try to avoid such unexpected outcomes. Furthermore, the positive relation between robot usage and PedsQL scores may be explained by other factors that were omitted in the current study (e.g., user motivation). Reverse causation may also exist. For example, students with better PedsQL scores may be more likely to use the robots more. To test these possibilities, future studies may follow a longitudinal design to better approximate a causal relation, as well as incorporate a measure of motivation.

The findings presented in this study lay the groundwork for future policies, interventions, and research. First, our results support the use of intelligent robots as an innovative resolution to the widespread social problem of inadequate care and educational resources for LBC. While this project has yielded promising results, other factors require that future studies collect data over an extended observation period. For example, more information is needed to support the robots' sustainability, including maintenance and disseminating software updates. We can anticipate that internet accessibility may hinder software updates, just as it posed a challenge to the proper functioning of the private conversation and parent communication features. As such, future improvements to the Xiao En Intelligent Robots project require further investigation into offline options and/or expanding internet coverage to rural areas. The findings can additionally promote the development of other programs to advance positive youth development and well-being (Shek et al., 2020; Zhu & Shek, 2020; Zhu & Shek, 2021).

This study provides information that can direct the future of the Xiao En Intelligent Robots project. We observe that the intelligent robots, so far, have a profound effect on LBC's functioning. Areas to improve include being mindful of the limitations of certain features, namely those that required stronger internet connectivity. From here, the Xiao En Intelligent Robots development team will need to address connectivity issues in rural areas; the AI system's conversation ability; and other logistics to better support parent-child interaction via the robot platform. The problems that arose during this study cannot be solved by any single entity. Unstable and weak internet connection will require professionals across disciplines to improve the availability of resources to LBC.

The findings of this study pave many different paths for future studies on technology-assisted child development. In our study, LBC had higher scores for social and school functioning. These differences went unexplained in our study. Future

studies should delve into the possible explanations for these higher functioning by examining the influence of the school setting on these types of functioning. In our study, we found that there are between-group differences in functioning for boys and girls. A follow-up study may further examine underlying explanations for boys' lower health-related child well-being scores. We also observed between-group differences based on family residence. Students from Sichuan province had lower health-related child well-being scores than those from Hunan province. As aforementioned, this study does not yield information regarding the robots' potential for sustainability. For now, the long-term effects of the robots are unknown. Future studies should gather longitudinal data in order to more accurately capture how the robots may impact child well-being over longer periods of time. Finally, using a qualitative study design may be more appropriate to elucidate users' subjective experiences with the Xiao En Intelligent Robots. This will give child users the opportunity to describe, in their own words, perceived impact of the robots on their lives.

Limitations

The results of this study have several limitations. We were limited to a small sample size and a small reference group because the Xiao En Intelligent Robots project was still in its infancy during the study period. Moreover, even though the regression results indicate robust effects of the use of intelligent robots on investigated outcomes, they may not be generalizable to all LBC due to the use of a small sample size. Therefore, a large, random sample and a reference group of comparable size are warranted to draw conclusions about the effects that products like the intelligent robots may have on the well-being of the larger LBC population. Furthermore, although our cross-sectional design supports a positive relation between robot use and child well-being, a future study using longitudinal data based on child samples in China would establish temporal order, better support a causal relation, and offer insight into potential mediation effects. For instance, Zhou et al. (2020b) conducted a longitudinal study of 2,648 students and found that positive youth development negatively predicted students' depression scores in a temporal sequence in China. Likewise, Zhou et al. (2020b) used a longitudinal study design to demonstrate that positive youth development predicted Chinese adolescents' increased life satisfaction and reduced hopelessness. Meanwhile, positive youth development at an earlier time predicted higher life satisfaction later through reduced hopelessness. Due to the nature of self-reporting, the data collected in this study are subject to reporting errors. Last, future studies can explore the negative effects of other electronic use, outside of the robots. Research can consider how the type of content being accessed on other devices might affect child well-being. For example, a child who is exposed to graphically violent media may be differently affected by electronic use than a child who is being exposed to educational videos. Overall, we find that Xiao En Intelligent Robots offer a promising alternative to other electronics. Addressing limitations in future studies can hopefully strengthen these results.

Conclusions

This study offers empirical evidence for technology-assisted child development and its ability to decrease differences between LBC and non-LBC. The Xiao En Intelligent Robots project presents a novel approach to a social problem that has been plaguing rural communities of China. Scant educational resources and inadequate parental care leave rural children behind their urban peers with regards to various outcomes but especially health-related well-being. This persistent problem demands an innovative solution that promotes positive child well-being within the LBC population. The Li Ensan Charity Foundation devised a unique product that delivers advanced supplementary educational and caretaking resources for LBC, showing great promise for the future of technology-based interventions.

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Declarations

Conflict of Interest The authors declare that they have no conflict of interest.

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