The mediating effect of information and communication technology usages on the nexus between assistive technology and quality of life among people with communication disability

Mohammad Afshar Ali, Khorshed Alam & Brad Taylor

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Abstract

The present study aims to investigate the mediating effect of ICT on the nexus between quality of life and assistive technology among people with communication disabilities. Using a national–level disability survey data in Australia, this study employs a series of causal mediation models based on counterfactual framework for mediation analysis. The results indicate that about 61% to 73% of the impact of assistive technology on quality of life among people with communication disabilities is mediated through ICT use. Furthermore, it is evident that the degree of communication impairment partially moderates the impact of ICT–enabled assistive technology on quality of life. The findings of the study have several practical implications. Firstly, this study indicates that better integration of assistive technology with ICT will enhance the quality of people with communication disabilities. The second broad recommendation is that improved accessibility with affordable high-speed broadband Internet can deliver services that people with disabilities need.

Keywords: Information and communication technology, assistive technology, quality of life, communication disability, causal mediation analysis.

1. Introduction

Information and communication technologies (ICTs) assist people with disabilities to navigate their day-to-day lives, providing greater access to education, employment, social interaction, culture, and health-related services [1-6]. According to a recent statistics, around 15% of the world's population suffers from some form of disability, and this is projected to increase in many societies with an ageing population [7]. Almost one in five Australians reported some form of disability (18.3% of the total population) [8]. Although only a small fraction of people with disabilities are people with communication disabilities, deficits in communication and interaction can have a seriously negative impact on quality of life [9-11]. ICTs are particularly important for people with communication disabilities insofar as they augment communication and interaction [6, 10, 12]. Though availability of ICT is regarded as one of the basic human rights in the Convention on the Rights of Persons with Disabilities [13], a number studies have revealed that people with disabilities are less likely than others to have a computer or Internet access at home [12, 14]. For example, 84.6% of the Australian population are Internet users [15] while for people with disabilities cohort the figure is substantially lower at 64.3% [8].

Studies have documented that ICTs have significantly enhanced the quality of life of people with disabilities by mitigating the disadvantages associated with disability. In particular, for people with communication disabilities, another strand of literature has reported that ICT–based interventions are associated with higher levels of health–related autonomy and reduction of communication impairment. In turn, these outcomes lead to greater social inclusion and improved quality of life [16-20]. In this connection, the use of ICT–based assistive technology among people with disabilities has received noticeable research attention [19, 21]. By definition, assistive technology is a piece of equipment or a device which helps people with disabilities to maintain their autonomy or improve their quality of life [22]. Examples of assistive technology aimed at people with communication disabilities include hearing aids, text-to-speech devices, and screen-reading software. Previous studies have shown that ICT–based assistive technology enhance quality of life by minimising communication– and interaction–related deficit faced by people with communication disabilities [19, 23]. In analysing the impact of ICT–based assistive technology on quality of life, scholars have controlled for a number of covariates including socio-demographic factors (age, gender, education and employment status), economic status (income), social exclusion (degree of discrimination faced and financial support from government) and location–specific factors (remoteness) [1, 2, 4, 19]. However, a number of issues in this area remained under-studied.

First, several studies in the field underscore the crucial role of ICT–assistive technology integration for independence, social integration, and betterment of overall quality of life of people with communication disabilities [19, 24, 25]. These studies also cautioned that in translating the positive impact of ICT–based assistive technology on quality of life, both incompatibly of assistive technology with ICT devices and inaccessibility of compatible ICT devices appeared as major barriers [26-28]. Given this backdrop, technology convergence between ICT and assistive technology helps promote equal opportunities and thus minimises the digital disability divide [21, 24, 26, 29]. This, in turn, implies that the effectiveness of assistive technology with regard to improving the quality of life among people with communication disabilities is subject to accessibility of compatible ICTs. However, to the best of authors' knowledge, existing studies yet to explore the mediating effect of ICT on the causal association between assistive technology and quality of life among people with communication disabilities.

Second, people with communication disabilities are not a homogeneous group, and they face different types of barriers depending upon their type and degree of impairment. Therefore, the way technology is utilised and its subsequent impact on quality of life among various groups of people with communication disabilities should be heterogeneous [12, 19]. In addition, the impact of ICT enabled assistive technology on quality of life among people with communication disabilities might also differ if disabled person has multiple impairment [18, 29]. Based on this motivation, it is assumed that the effect of ICT–based assistive technology on quality of life is heterogeneous subject to the extensity of communication impairment among people with communication disabilities. This gives a solid motivation to explore the heterogeneity of the impact of ICT enabled assistive technology on quality of life among people with communication disabilities which has yet to be revealed by empirical study.

Given this backdrop, the present study aims to investigate the mediating effect of ICT on explaining the nexus between assistive technology and quality of life among people with communication disabilities. To achieve this research objective, two research questions are posed: (i) whether or not ICT mediates the causal association between assistive technology and quality of life among people with communication disabilities, and (ii) whether or not the impact of ICT–based assistive technology on quality of life is heterogeneous with respect to the extent of communication impairment among people with communication disabilities. This study makes a number of noteworthy contributions to the literature. First, it constructs a composite index to measure the quality of life for people with communication disabilities cohort. In constructing the composite quality of life index, the current study follows the World Health Organisation Quality of Life (WHOQoL) disabilities module [30] which constructed the composite quality of life for people with disabilities using a number of indicators from five distinctive domains – physical, psychological, social, environment, and disabilities module (see Section 2.1 for details). Using that composite index, the current research investigates the mediating role of ICT in explaining the quality of life–assistive technology association among people with communication disabilities employing advanced causal mediation analysis. Second, the current study also explores whether the mediating effect of ICT on quality of life–assistive technology nexus varies with the degree of communication impairment. Third, to avoid the potential bias that may arise from the sampling procedure, it uses both perception– and condition–based definition to define communication disability (see Section 2.1 for more details). Findings from the current study are expected to generate better insights from policy perspectives as the study is based on a comprehensive nation–wide cross–sectional survey equipped with improved estimation techniques.

2. Materials and Methods

2.1. Data and variables

The current study used the Australian Bureau of Statistics (ABS) Microdata – Basic Confidentialised Unit Record Files (CURF) compiled through the 2015 Survey of Disability, Ageing and Carers (SDAC). The survey methodology is explained in detail in ABS [8]. The survey was conducted across all states and territories, and in all urban, rural and remote areas of Australia. Data collection consists of two parts: the establishment component and the household component. Accommodation within establishments is comprised of hospitals, aged care facilities, nursing homes, cared components of retirement villages and other homes for people with disabilities. The final combined sample consists of 75,211 people, including 23,343 with a disability.

The cohort for this study has been selected on the basis of two criteria: (i) respondent's perception on whether or not they have a communication impairment, and (ii) whether or not the respondent reports medical conditions that may result in communication impairment. The list of conditions developed for the SDAC is based on the International Classification of Disease (ICD-10) (see Supplementary Table S1 for details). Of the 23,343 respondents with a disability, 10,866 reported having difficulty communicating due to their disability (i.e. satisfied criterion [i]), and 8,515 reported having one of the relevant medical conditions (i.e. satisfied criterion [ii]). There were 6,137 respondents meeting both criteria, and it is this group we use as the sample for this study.

The sampling procedure in earlier studies have used either one of the above criteria. For example, some studies defined communication impairment using the respondent's perception [3, 14, 29], while others relied on reported or diagnosed medical conditions [17, 19, 25, 31]. However, each definition has its own limitations. Following the first criterion may result in bias since it is a perception-based definition. Self-rated status of outcome is a subjective measure, perception of which can be affected by other factors, including social circumstances [32, 33]. Similarly, defining communication impairment on the basis of reported medical conditions may be misleading as many such conditions do not consistently produce communication disabilities. To be specific, in the 2015 SDAC, a total of 2,378 disabled people who reported having a relevant medical condition did not see themselves as suffering from a communication impairment. Considering these facts together, this study defines the sample of people with communication disabilities as those who satisfy both conditions – i.e. those suffering from a relevant medical condition AND reporting communication difficulties.

Table 1 provides the definitions of the variables included in the models along with their means and standard deviations. The classification of the variables also reflects the model specifications as outlined in Table 1. The variables listed in panel A is the outcome variable, those in panel B is the treatment variable, panel C and D list mediating and moderating variables, respectively, and those in panel E are included as control variables in both output and mediating regression models.

The Principal Component Analysis (PCA) is used to construct the composite index of quality of life. Building a composite index considered to be is a better approach than modelling equations with separate indicators as it inherits the aggregate effect of all indicators [34]. The following equation is used to construct the composite index, *QoL*:

$$QoL = \sum_{i=1}^{3} a_{ij} \frac{X_i}{SD(X)_i} \qquad (1)$$

where *QoL* is the composite index measuring the quality of life of an individual, SD is the standard deviation, X_i is the *i*th variable, and a_{ij} is the factor loading derived through the PCA.

2.2. Model specification and estimation methods

2.2.1. Causal mediation analysis

Mediation analysis explores the apparatus that cause an observed relationship between an exposure variable and outcome variable, and investigates how they relate to a third mediator or intermediate variable. The baseline results of the regression model are estimated using two counterfactual parametric causal mediation regression models – parametric causal mediation regression models and parametric mediation effects. In addition, the current study employs another causal mediation regression model based on G-computation procedure in order to check the robustness of the two-baseline counterfactual causal mediation regression models. A detailed description on the rationale of using these three causal mediation regression models is provided in the Supplementary Materials. Causal mediation mechanism among the variables investigated is portrayed in Figure 1.

2.2.2. Moderation analysis

A moderation analysis is used to explore when, or under what circumstances, or for which group of sub-sample the causal effect of mediator and treatment on the outcome exists or does not, and if exists what is the magnitude [35]. The current study hypothesises that the causal effect of ICT enabled assistive technology will vary with the degree of communication impairment. For details on moderation analysis, see the Supplementary Materials. Figure 2 illustrates the moderation effect of degree of communication impairment on the nexus between ICT enabled assistive technology and quality of life.

3. Empirical results

3.1. Causal mediation effect

3.1.1. Main results

The results of causal mediation using parametric causal mediation regression models *(-paramed-)* are presented in Table 2. The results of both the outcome and mediation regression models and the summary estimates of the mediation, direct and total effects are provided here. The regression coefficients of the outcome equation [Eq. (2)] show that both *AT_COM_USE* and *ICT_USE* has a positive and significant effect on QoL. The coefficient of the interaction effect between assistive technology use and ICT use *(ICT_USE×AT_COM_USE)* is also positively associated with *QoL*. Among socio–demographic variables – EDU, EMPOLY, AGE and GENDER appeared as significant predictors of QoL. However, estimates also come up with an interesting finding that *DISAB_SUP* is found to have a negative impact on the *QoL* among people with communication disabilities. At the same time, the results from mediation equation [Eq. (3)] indicate that ICT*_USE* is dependent upon *AT_COM_USE*. The NIE of the treatment variable on the outcome which operates through the mediator (ICT_USE) is 0.362, and the estimate of the NDE is equal to 0.157. Hence, the indirect or mediation effect represents 70.1% of the total effect while direct effect accounts 29.9% of the total effect. In other words, more than two-third of the effect of assistive technology on quality of life is mediated through ICT.

The Stata outputs from the two regression models [Eq. (2) and (3)] using the parametric mediation effect model (-*medeff*-) along with summary estimates of different effects are reported in Table 3. The results of both outcome and mediation equation are quite similar to the corresponding estimates represented in Table 2. The mediating effect of the treatment variable (i.e. *AT_COM_USE*) on the outcome variable (*QoL*) that mediates through *ICT_USE* is 0.305 while the direct effect of *AT_COM_USE* on *QoL* is 0.198. These figures imply that 60.8% of the total effect of assistive on quality of life is mediated through ICT.

3.1.2. Sensitivity and robustness checks of causal mediation analysis

The results of sensitivity analyses for the estimations conducted in the preceding section are recorded in Supplementary Table S2. To do this, the Stata command (-*medsens-)* is used which automatically detects which type of sensitivity analysis needs to be conducted [36]. The value of ρ [correlation between the error terms of Eq. (1) and Eq. (2)] where the ACME is zero along with the sensitivity to both types of R^2 expressions are presented in the table. Here, the rule of thumb is that the larger the value of ρ, the greater will be the chance of having strong confounding between the mediator and the outcome. This, in turn, indicates that there could be a serious violation of the sequential ignorability assumption [36]. However, the results suggest that the point estimate of the ACME equals to zero when ρ is below 0.514. Alternatively, for the point estimate of the ACME to be zero, the correlation between u_y and u_m must be approximately 0.264. This indicates a moderate degree of robustness [37].

To check the robustness of the results of causal mediation analysis reported in Section 3.1.1, the abridged output of the causal mediation using G-computation formula is recorded in Table 4. The results conclude that *AT_COM_USE* has a causal effect on *QoL* which is basically mediated through *ICT_USE*. The use of assistive technology for communication purpose improves the quality of life by 0.204 units (95% CI [0.174, 0.234]). A majority of this development (73.2%) is mediated through ICT usage. This indicates use of ICT enabled assistive technology will augment the quality of life among people with communication disabilities by 0.150 units (on a 5 point scale) on average (95% CI [0.121, 0.178]). This, in turn, indicates that the remaining 26.8% of the total effect of *AT_COM_USE* (0.055 units) on *QoL* is direct (95% CI [0.027, 0.082]).

3.2. Moderation effect

The results from basic moderating effect estimation are populated in Table 5. The results suggest that the impact of ICT enabled assistive technology (*ICT_AT_USE*) on QoL is contingent upon the degree of communication impairment (*LVLCOMMR*) of the respondents as the coefficient of *ICT_AT_USE* is statistically significant. In particular, whereas for disabled persons with mild communication impairment, a one standard deviation increase in *ICT_AT_USE,* enhances the outcome (i.e. quality of life) by 0.380 standard deviations, for those with severe or profound communication impairment the resultant change is negligible (0.002 standard deviations) (see Supplementary Table S3 and S4). In turn, the results reported in Table 5 indicate that the impact of the interaction between ICT enabled assistive technology use and level of communication impairment (*ICT_AT_USE*× *LVLCOMMR*) on quality of life among people with communication disabilities is negative. This suggests that those with severe communication impairments lack effective assistive technologies to assist them in using ICTs for communication purposes.

4. Discussion and Conclusion

The major finding of the study indicates that the use of assistive technology for communication purposes among people with communication disabilities has a causal effect on their quality of life, most of which is mediated through ICT use. To be specific, the results from the three different causal mediation models indicate that about 61% to 73% of the impact of assistive technology on quality of life is indirectly mediated through ICT use while the direct impact of assistive technology on the quality of life accounts 27% to 39%. These results suggest that for people with communication disabilities the compatibility of assistive technology with suitable ICT devices is one of the major prerequisites in yielding the best possible outcome from the perspective of the quality of life–assistive technology nexus. In line with this finding, a number of existing empirical works have emphasised the importance of the integration of ICT and assistive technology for the enhancement of quality of life among people with communication disabilities [19, 24, 25].

The regression-based causal mediation analysis also indicates that apart from ICT and assistive technology use, several economic and socio-demographic factors significantly predicts the quality of life among people with communication disabilities. As we would expect, higher personal income, education, and employment status are associated with greater quality of life. Further, age is negatively associated with quality of life of people with communication disabilities. These findings are consistent with the findings of existing empirical research [2, 4, 19].

It is also evident that the degree of communication impairment partially moderates the impact of ICT enabled assistive technology on quality of life among people with communication disabilities. For respondents with mild communication impairment the impact of ICT enabled assistive technology on quality of life is much higher than that of respondents with severe or profound communication impairment. This indicates a lack of availability and appropriateness of assistive technology for those with the most severe communication impairments. These findings accord with the results reported by a number of prior studies [12, 19].

The current study makes a number of novel contributions. First of all, instead of investigating only the direct impact of ICT-based assistive technology on quality of life, the current study explores the mediating impact of ICT in translating the effect of assistive technology on quality of life among people with communication disabilities. In addition, in defining the quality of life, unlike previous studies [3, 19, 25, 29], this study builds on a comprehensive composite quality of life index following the WHOQoL disabilities module which is consisted of indicators from five distinctive domains – physical, psychological, social, environment, and disabilities module. Moreover, by combining perception and condition-based definitions of communication disability, the current study checks for potential biases that may arise from incorrect sampling procedure. Last but not the least, the study also explores whether or not the mediating effect of ICT on quality of life–assistive technology nexus is heterogeneous with respect to the degree of communication impairment.

The findings of the study have several practical implications. First of all, this study indicates that better integration of assistive technology with ICT will enhance the quality of life of people with communication disabilities. This suggests a series of possible actions for the government and other actors in the disability sector. First, better integration of assistive technology with ICT requires that carers and disability service providers need to acquire knowledge and skills on assistive technology and ICT use. Targeted training is the most plausible way of pursuing this goal, and here the government could collaborate with private and other non-government agencies to deliver effective ICT–assistive technology training. Second, mainstream ICT devices (e.g. mobile and landline phones, television, and Internet) are often incompatible with available assistive technology. To overcome this hurdle, application of principles of universal design in programmes run by the government, business and non-government organisations can maximise the usage and accessibility of such programmes. Finally, the finding that those with severe or profound communication impairment fail to reap the benefits of ICT suggests that a broader range of assistive technologies catering to these groups is needed.

A second broad recommendation is that improved accessibility with affordable high-speed broadband Internet can deliver services that people with disabilities need. To promote ICT accessibility for people with disabilities, the National Disability Insurance Agency (NDIA) is working on building its long-term ICT infrastructure [38]. In this regard, initiatives such as providing access to high-speed affordable Internet through the National Broadband Network (NBN) can be handy. Improved ICT accessibility for people with communication disabilities can be also attained by integrating market regulation and anti-discrimination approaches in relevant public procurement procedures and consumer protection laws.

However, the current study is not free from limitations, and further work is required to build on our understanding of the connections between ICT, assistive technologies, and quality of life of people with communication disabilities. Firstly, we couldn't accommodate support received from NDIS as an explanatory variable in the regression models, since the SDAC survey was conducted in 2015, before the NDIS rollout was completed. Therefore, less than 1% of respondents reported to have access to NDIS. In addition, the relative standard error of the corresponding variable is a greater than 50% which requires further investigation. To be precise, standard error gives a hint of the likely precision of the sample mean compared to the population mean. The larger the standard error, the smaller will be the accuracy of the results. Further studies investing the impact of support received through NDIS on quality of life among people with communication disabilities would be worthwhile.

Secondly, the conclusions drawn are based solely on Australian data, and it is possible that cross-country differences in institutions, economic circumstances, and culture might limit the generalisability of these findings to other countries. Further work using data from other countries would therefore be valuable, and until such work has been done the findings of the current study should be extended to other countries with caution.

Lastly, although the survey data used in this study allows for a rigorous test of the hypotheses presented above, more detailed qualitative analysis would no doubt add a great deal of depth to our understanding of the determinants of and barriers to the usage of ICT enabled health services among people with communication disabilities. In this regard, in-depth focus group discussions with people with communication disabilities, particularly those residing in rural and remote areas, would provide further details on how precisely utilisation is constrained by ICT artefacts (e.g. digital skills, affordability and accessibility) and individual behavioural aspects (e.g. age, level of education, lack of trust and time and degree of impairment).

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Table

Table 1: Variable descriptions and summary statistics.

Variable name	Definition of variable	Mean	SD
A. Outcome variable			
QoL	A composite index to measure the QoL for the respondent with a communication impairment. This includes– (i) level of mobility limitation, (ii) level of negative feelings, (iii) level of social or community participation, (iv) feelings of safety, and (v) level of self-care limitation. All five indicators are categorical and measured on a 5 point Likert scale. The five indicators used in the current study is selected from five respective domains (viz. – physical, psychological, social, environment and disabilities module) to define the overall quality of life of disabled people (WHO, 2011a).	2.034	0.808
B. Treatment or exposure variable			
AT_COM_USE	A dummy variable indicating whether or not the respondent has used assistive technologies for communication purposes (1= has used assistive technology for communication purposes, 0 = has not used assistive technology)	0.333	0.471
C. Mediating variable			
ICT_USE	A dummy variable indicating whether or not the respondent has used at least one type of ICT tools from the following in the last 3 months to communicate with others. This includes use of mobile phone, telephone, Internet, social networking apps and disability specific apps for communication purposes (1= has used ICT for communication purposes, 0= otherwise)	0.185	0.389
D. Moderator variable			
LVLCOMMR	A dummy variable indicating the level of communication impairment of the respondent (1 = profound or severe, 0 = mild)	0.819	0.385
E. Control variables			
WHODISC	A categorical variable indicating degree of discrimination that the respondent has experienced due to disability in the last 12 months (1 = very low, 2 = low, 3 = moderate, 4 = high, and 5 = very high)	1.002	0.064
INCDECPN	A categorical variable indicating the quantile of the respondent's personal income (1 = 1st quantile, 2 = 2nd quantile, 3 = 3rd quantile, 4 = 4th quantile, and 5 = 5th quantile)	2.067	0.444
EDU	A categorical variable indicating the respondent's highest level of educational attainment (1 = Year 12 or below, 2 = Certificate III or IV, 3 = Advanced diploma, 4 = Bachelor, 5 = Postgraduate)	1.118	0.536
EMPLOY	A dummy variable indicating the labour force status of the respondent (1 = employed , 0 = otherwise)	0.036	0.185
AGE	A categorical variable indicating the age group of the respondent (1= 0-14 years, 2 = 15-29 years, 3 = 30-44 years, 4 = 45-59 years, 5 = above 60 years)	4.591	1.079
GENDER	A dummy variable indicating the gender of the respondent (1 = male , 0 = female)	0.413	0.492
DISAB_SUP	A dummy variable indicating whether or not the respondent received disability support payment from the government.	0.025	0.156
REMOTE	A dummy variable indicating whether or not a respondent person lives in a remote area (1= resident of a remote area, 0 = otherwise).	0.117	0.321
Number of observations		6137	

Table 2: Causal mediation analysis using parametric causal mediation regression models *(-paramed-)*.

Output equation: Dependent variable - QoL			
Variable	**Coefficient**	**SE**	**t-statistics**
AT_COM_USE	0.066*	0.0142	4.670
ICT_USE	0.762*	0.0302	25.260
ICT_USE×AT_COM_USE	0.832*	0.0353	23.560
WHODISC	-0.112	0.0864	-1.300
INCDECPN	0.112*	0.0154	7.250
EDU	0.109*	0.0128	8.560
EMPLOY	0.156*	0.0361	4.310
AGE	-0.143*	0.0061	-23.460
GENDER	0.051*	0.0115	4.410
DISAB_SUP	-0.308*	0.0371	-8.310
REMOTE	0.019	0.0172	1.110
Constant	2.151*	0.0965	22.310
F-statistics		1411.770*	
R-squared		0.717	
Number of observations		6137	
Mediation equation: Dependent variable - ICT_USE			
Variable	**Coefficient**	**SE**	**t-statistics**
AT_COM_USE	0.231*	0.008	28.280
INCDECPN	0.089	0.057	1.550
EDU	0.062*	0.010	6.090
EMPLOY	0.211*	0.008	26.520
AGE	0.248*	0.024	10.450
GENDER	-0.112*	0.004	-31.260
Constant	0.024*	0.008	3.150
F-statistics		581.250*	
R-squared		0.460	
Number of observations		6137	
Effects			
Effect	**Estimate**	**[95% Conf. Interval]**	
CDE	0.898*	0.835	0.962
NDE	0.157*	0.130	0.184
NIE	0.368*	0.341	0.396
MTE	0.525*	0.492	0.557

Notes: *, ** and *** denote statistically significant at 1%, 5% and 10%, respectively.
CDE = Controlled Direct Effect, NDE = Natural Direct Effect, NIE = Natural Indirect Effect, and MTE= Marginal Total Effect.

Table 3: Causal mediation analysis using parametric mediation effect models (-*medeff*-).

Output equation: Dependent variable - QoL			
Variable	**Coefficient**	**SE**	**t-statistics**
AT_COM_USE	0.198*	0.014	14.530
ICT_USE	1.309*	0.020	65.190
WHODISC	-0.043	0.090	-0.470
INCDECPN	0.150*	0.016	9.310
EDU	0.147*	0.013	11.130
EMPLOY	0.190*	0.038	5.040
AGE	-0.100*	0.006	-16.500
GENDER	0.054*	0.012	4.560
DISAB_SUP	-0.377*	0.039	-9.770
REMOTE	0.025	0.018	1.400
Constant	1.732*	0.099	17.500
F-statistics		1373.230*	
R-squared		0.692	
Number of observations		6137	
Mediation equation: Dependent variable - ICT_USE			
Variable	**Coefficient**	**SE**	**t-statistics**
AT_COM_USE	0.234*	0.008	28.240
INCDECPN	0.057*	0.010	5.500
EDU	0.208*	0.008	25.830
EMPLOY	0.288*	0.024	12.040
AGE_REC	-0.123*	0.004	-34.520
GENDER	0.027*	0.008	3.420
Constant	0.300*	0.025	12.080
F-statistics		813.250*	
R-squared		0.443	
Number of observations		6137	
Effects			
Effect	**Mean**	**[95% Conf. Interval]**	
ACME	0.305*	0.284	0.329
DE	0.198*	0.170	0.224
TE	0.504*	0.472	0.535
% of TE mediated	0.608*	0.572	0.648

Notes: *, ** and *** denote statistically significant at 1%, 5% and 10%, respectively.
ACME= Average Causal Mediation Effect, DE = Direct Effect, and TE= Total Effect.

Table 4: Causal mediation analysis using G-computation procedure (-*gformula*-) (abridged output).

Effect	**G computation estimate**	**Bootstrap SE**	**z-statistics**	***p*-value**	**Normal-based [95% Conf. Interval]**	
TCE	0.204*	0.015	13.350	0.000	0.174	0.234
NDE	0.055*	0.014	3.920	0.000	0.027	0.082
NIE	0.150*	0.015	10.270	0.000	0.121	0.178

Notes: *, ** and *** denote statistically significant at 1%, 5% and 10%, respectively.
TCE = Total Controlled Effect, NDE = Natural Direct Effect, and NIE = Natural Indirect Effect.

Table 5: Moderating effect of degree of communication impairment on the relationship between ICT enabled AT and QoL.

Variable	**Coefficient**	**SE**	**t-statistics**
AT_COM_USE	0.891*	0.043	20.870
ICT_USE	1.434*	0.046	31.100
WHODISC	-0.250*	0.077	-3.260
INCDECPN	0.061*	0.014	4.460
EDU	0.054*	0.011	4.710
EMPLOY	0.118*	0.032	3.690
AGE	-0.196*	0.006	-35.120
GENDER	0.056*	0.010	5.510
DISAB_SUP	-0.142*	0.033	-4.250
REMOTE	0.005	0.015	0.340
ICT_AT_USE	0.982*	0.034	28.670
ICT_AT_USE×LVLCOMMR	-0.467*	0.020	-23.650
LVLCOMMR	0.453*	0.049	9.170
Constant	3.176*	0.090	35.300
F-statistics		1644.950*	
R-squared		0.777	
Number of observations		6137	

Note: *, ** and *** denote statistically significant at 1%, 5% and 10%, respectively.

Figure

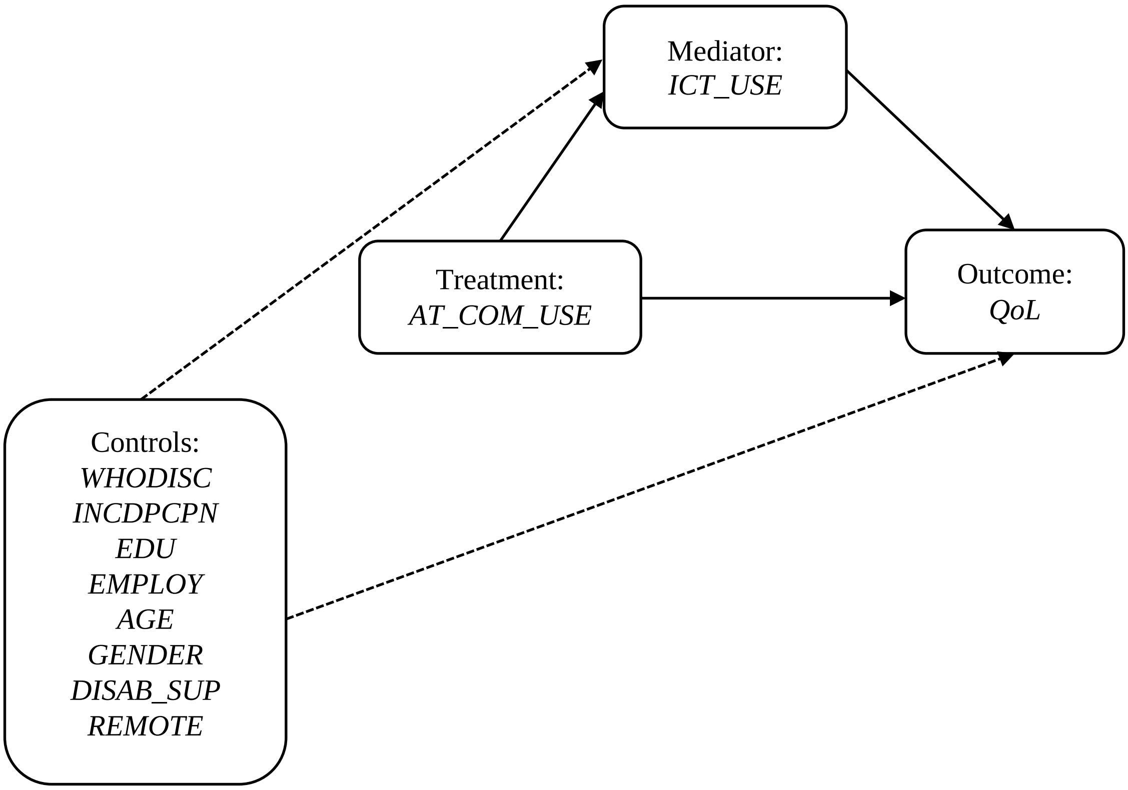

Figure 1: Causal mediation mechanism among the variables investigated.

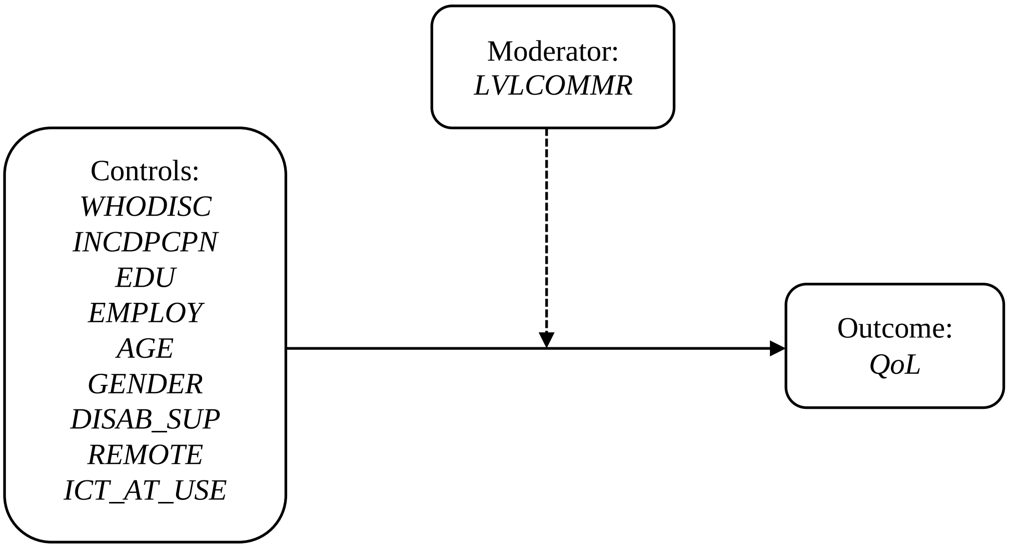

Figure 2: Moderation effect of degree of communication impairment on the nexus between ICT enabled assistive technology and quality of life.

Supplementary Materials

I. Model specification and estimation methods

Causal mediation analysis

Mediation analysis explores the apparatus that cause an observed relationship between an exposure variable and outcome variable, and investigates how they relate to a third mediator or intermediate variable. This study uses the counterfactual framework for mediation analysis [1-5] which allows for decomposition of total effects into direct and indirect effects in settings where non-linearities and interactions are present. This is a methodological improvement over the classical mediation analysis of Baron and Kenny [6]. Among a number of counterfactual causal mediation regression models, the current study uses the following three models to carry out the empirical analysis due to their suitability over others in this particular context.

Parametric causal mediation regression models (-paramed-)

To extend the classical regression–based mediation analysis, VanderWeele and Vansteelandt [5] used the counterfactual framework by deriving results for direct and indirect effects for linear and logistic regressions in the presence of exposure–mediator interaction. Valeri and VanderWeele [4] extend this work by allowing dichotomous mediators in the mediation analysis for parametric models.

Within the framework of current study, there is a continuous outcome and a binary mediator, the outcome regression model and mediation regression model can be formulated, respectively, as follows:

$$E[y|a,m,c] = \theta_0 + \theta_1 a + \theta_2 m + \theta_3 am + \theta'_4 c + u_y \quad (2)$$

$$logit\ [p(m=1|a,c)] = \beta_0 + \beta_1 a + \beta'_2 c + u_m \quad (3)$$

where, a = exposure, m = mediator, y = outcome, c = covariates. In this study, the exposure is AT_COM_USE, the mediator and outcome variable are ICT_USE and QoL, respectively (see Table 1 for details).

If the covariates c satisfy the no-unmeasured confounding assumptions [4], then controlled direct effect (CDE), average natural direct effect (NDE) and average natural indirect effect (NIE) would be given by:

$$CDE = (\theta_0 + \theta_1 m)\,(a - a^*) \quad (4)$$

$$NDE = \theta_1 (a - a^*) \ + \{\theta_3 (a - a^*)\} \frac{\exp\,(\beta_0 + \beta_1 a^* + \beta'_2 c)}{1 + \exp\,(\beta_0 + \beta_1 a^* + \beta'_2 c)} \quad (5)$$

$$NIE = (\theta_2 + \theta_3 a) + \frac{\exp\,(\beta_0 + \beta_1 a + \beta'_2 c)}{1 + \exp\,(\beta_0 + \beta_1 a + \beta'_2 c)} - \frac{\exp\,(\beta_0 + \beta_1 a^* + \beta'_2 c)}{1 + \exp\,(\beta_0 + \beta_1 a^* + \beta'_2 c)} \quad (6)$$

Parametric mediation effects (-medeff-)

Another counterfactual causal mediation analysis was developed by Imai, Keele and Tingley [3] which can integrate parametric and non-parametric models, linear and non-linear relationships, continuous and discrete mediators and different types of outcome variables. Considering the outcome regression model and mediation regression model, outlined respectively in Eq. (2) and (3), the average causal mediation effect (ACME), the direct effect (DE) and average total effect (TE) can be expressed as follows:

$$ACME = E\big[y_i\big(a, m_i(1)\big) - y_i\big(a, m_i(0)\big)\big] \quad (7)$$

$$DE = E\big[y_i\big(1, m_i(a)\big) - y_i\big(0, m_i(a)\big)\big] \quad (8)$$

$$TE = E[y_i\big(1, m_i(1)\big) - y_i\big(0, m_i(0)\big)] = \frac{1}{2}\ [ACME + DE] \quad (9)$$

Imai, Keele and Tingley [3] advocated running a sensitivity analysis once the causal mediation has been conducted. This analysis examines the degree of the sensitivity of the results to the violation of the SI assumption.

G-computation procedure (-gformula-)

In estimating causal mediation, a methodological problem arises if there exist other confounders which might influence the mediator-outcome (*m*–*y*) relationship. If such confounders exist, the causal mediation regression models may yield inconsistent estimates of the direct effect of the treatment (*a*) on the outcome (*y*). To overcome this complexity, Daniel, De Stavola[1] developed the G-computation procedure. The current study employs this procedure in order to check the robustness of the two-baseline counterfactual causal mediation regression models.

Taking the outcome regression model and mediation regression model outlined respectively in Eq. (2) and (3), the total controlled effect (TCE), the natural direct effect (NDE) and natural indirect effect (NIE) can be written as follows:

$$TCE = [y(a, m(a))] - E[y(0,m(0))] \quad (10)$$

$$NDE = E[y(a, m(0))] - E[y(0, m(0)] \quad (11)$$

$$NIE = E[y(a, m(x))] - E[y(x, m(0))] \quad (12)$$

Moderation analysis

A moderation analysis is used to explore when, or under what circumstances, or for which group of sub-sample the causal effect of mediator and treatment on the outcome exists or does not, and if exists what is the magnitude [7]. The term ‘interaction’ is also interchangeably used with ‘moderation’. If *x*’s effect on *y* is moderated by *w*, then *x* and *w* are interacting each other.

The current study hypothesises that the causal effect of ICT enabled assistive technology will vary with the degree of communication impairment. For the current analysis, the simple linear regression without the interaction effect can be expressed as follows:

$$\hat{y} = \beta_0 + \beta_1 ICT\_AT\_USE + \beta_2 LVLCOMMR + \wedge Z + u \quad (13)$$

where, y = QoL, *ICT_AT_USE*= the interaction between the ICT and assistive technology use, *LVLCOMMR*= level of communication impairment, Z = covariates, and u = error term.

But, as specified in Eq. (13), the effect on *ICT_AT_USE* on *QoL* is fixed to be the same– β_1 – regardless of the value of moderating variable *LVLCOMMR*. By testing the moderation hypothesis, this constraint on *ICT_AT_USE* can be eradicated. This can be done by specifying the effect of *ICT_AT_USE* as a function of *LVLCOMMR*. Substituting ($\beta_1+\beta_3$ *LVLCOMMR) for* b_1 in Eq. (13), the following expression will be obtained

$$\hat{y} = \beta_0 + (\beta_1 + \beta_3\, LVLCOMMR)\, ICT\_AT\_USE + \beta_2 LVLCOMMR + \wedge Z + u \quad (14)$$

Mathematically, this is equivalent to

$$\hat{y} = \beta_0 + \beta_1 ICT\_AT\_USE + \beta_2 LVLCOMMR + \beta_3\, (LVLCOMMR \times ICT\_AT\_USE) + \wedge Z + u \quad (15)$$

If the effect of interaction *(LVLCOMMR× ICT_AT_USE)* measured by β_3 does not equal zero, then it can be claimed that the effect of *ICT_AT_USE* on *QoL* varies with the *LVLCOMMR*, i.e. *LVLCOMMR* moderates the impact of *ICT_AT_USE* on *QoL*.

II. Supplementary Table

Table S1: List of conditions that may affect communication ability.

SN	Condition	ABS Code	ICD-10 Code
1	Mental and behavioural disorders	500	F00–F99
2	Dementia	511	F00–03
3	Schizophrenia	512	F20
4	Intellectual and developmental disorders	530	F80–89
5	Mental retardation/intellectual disability	531	F70–F79
6	Autism and related disorders (including Rett's syndrome and Asperger's syndrome)	532	F84
7	Other developmental/learning disorders	539	F80.1–F80.9, F83, F88–89
8	Attention deficit disorder/hyperactivity	595	F90
9	Speech impediment	596	F98.5
10	Other mental and behavioural disorders	599	F04–09, F51.1–52, F54–55, F59, F99
11	Parkinson's disease	604	G20–21
12	Alzheimer's disease	605	G30
13	Brain disease/disorders—acquired	606	G45–G46, G90–93.2, G93.4–G94.8
14	Multiple sclerosis	607	G35
15	Cerebral palsy	611	G80
16	Diseases of the middle ear and mastoid	802	H65–75
17	Diseases of the inner ear	803	H80–83.2, H83.8–83.9
18	Deafness/hearing loss	810	H83.3, H90–H91
19	Deafness/hearing loss—noise induced	811	H83.3
20	Deafness/hearing loss—congenital	812	H90
21	Deafness/hearing loss—due to accident	813	No ICD–10 equivalent
22	Other deafness/hearing loss	819	H91.0–91.3, H91.9
23	Other diseases of the ear and mastoid process	899	H92–95
24	Stroke	923	I64
25	Congenital brain damage/malformation	1605	Q00–04
26	Unspecified speech difficulties	1705	R47.0, R47.8–48
27	Memory loss	1709	R41.1–41.3
28	Dysphagia (difficulty in swallowing)	1713	R13
29	Head injury/acquired brain damage	1801	S00–09
30	Memory problems or periods of confusion	1908	N/A

Table S2: Sensitivity analysis using *medsens.*

Rho *(ρ)* at which ACME = 0	0.514
R^2_M*R^^{2}_Y* at which ACME = 0	0.264
R^^{2}_M~R^^{2}_Y~ at which ACME = 0	0.068

Table S3: Standardized estimates of QoL for cluster with profound communication impairment.

Variable	**Standardized Coefficient**	**t-statistics**	**bStdX**	**bStdY**	**BStdXY**	**SDofX**
AT_COM_USE	-0.019	-0.230	-0.006	-0.020	-0.006	0.312
ICT_USE	0.883	8.776	0.405	0.925	0.424	0.459
WHODISC	-0.154	-1.431	-0.023	-0.161	-0.024	0.150
INCDECPN	0.029	1.379	0.027	0.031	0.028	0.918
EDU_REC	0.023	1.349	0.025	0.024	0.026	1.092
EMPLOY_REC	0.171*	3.288	0.063	0.180	0.066	0.366
AGE_REC	-0.064	-3.694	-0.066	-0.067	-0.069	1.027
GENDER_REC	0.132*	4.066	0.066	0.139	0.069	0.500
DISAB_SUP	-0.294*	-3.438	-0.059	-0.308	-0.062	0.200
REMOTE_REC	-0.011	-0.244	-0.004	-0.011	-0.004	0.365
ICT_USE*AT_COM_USE	0.755*	7.078	0.363	0.791	0.380	0.481
F-statistics			226.110*			
R-squared			0.694			
Number of observations			1109			

Note: *, ** and *** denote statistically significant at 1%, 5% and 10%, respectively.

Table S4: Standardized estimates of QoL for cluster with profound communication impairment.

Variable	**Standardized Coefficient**	**t-statistics**	**bStdX**	**bStdY**	**BStdXY**	**SDofX**
AT_COM_USE	-0.013	-1.055	-0.005	-0.027	-0.011	0.4071
ICT_USE	0.372*	13.464	0.096	0.799	0.207	0.2585
WHODISC	-0.145	-1.431	-0.021	-0.151	-0.023	0.151
INCDECPN	0.031	1.425	0.031	0.035	0.026	0.929
EDU_REC	0.161*	5.394	0.026	0.344	0.055	0.1597
EMPLOY_REC	0.239*	7.690	0.022	0.512	0.046	0.0899
AGE_REC	0.118**	2.029	0.128	0.252	0.275	1.0899
GENDER_REC	-0.238*	-43.537	-0.116	-0.510	-0.249	0.4877
DISAB_SUP	0.027	2.791	0.004	0.059	0.009	0.1443
REMOTE_REC	-0.062***	-1.736	-0.019	-0.133	-0.041	0.3102
ICT_USE*AT_COM_USE	0.007	0.464	0.001	0.015	0.002	0.1563
F-statistics			508.450*			
R-squared			0.503			
Number of observations			5028			

Note: *, ** and *** denote statistically significant at 1%, 5% and 10%, respectively.

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