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Smartphone-Based Technology to Help Individuals with Intellectual Disability and Blindness Manage Basic Indoor Travel

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Abstract

Objectives The present study assessed a new intervention strategy to help individuals with severe to profound intellectual disability and blindness (i.e., total blindness or minimal residual vision) to travel to different rooms located on both sides of long hallways.

Methods The intervention strategy was based on the use of a smartphone (i.e., a Samsung Galaxy J4 Plus with Android 9.0 operating system) and battery-powered light sources. The smartphone was programmed to encourage the participant to walk forward alongside a wall of the hallway until its light sensor was activated by a light source positioned before a room entrance. At that point, the smartphone encouraged the participant to stop and then enter. Nine participants were involved in the study. Each session involved seven travels.

Results During the baseline phase, the participants' mean frequencies of correct travels per session varied between zero and slightly above 2. During the intervention phase, with the smartphone-based cues, all participants showed a strong performance improvement. Their mean frequencies of correct travels varied between about 6.5 and (virtually) 7 per session during the second half of the intervention phase.

Conclusions This smartphone-based intervention strategy might help support indoor travel of people with intellectual disability and blindness.

Keywords Indoor travel · Orientation · Smartphone · Light sources · Intellectual disability · Blindness

Individuals with severe to profound intellectual disability, particularly if affected by blindness (i.e., total blindness or minimal residual vision), tend to have orientation and travel failures even within indoor areas familiar to them. For example, they may fail to recognize and enter the rooms where they are expected to bring objects and meet people. Instead, they may enter the first room they find on their way or continue to walk without entering any rooms (Besden 2007; Joffee and Rikhye 1991; Lancioni et al. 1995, 2010a, b; Uslan et al. 1983, 1988). These types of failures are difficult to remedy, as they imply the individual's lack of spatial awareness. Even so, they need to be addressed because travel engagement (goal-directed ambulation) is considered important for the individual's functional occupation, well-being, and social image (Bartlo and Klein 2011; Hill et al. 2015; Taylor et al. 2016).

Trying to help these individuals develop maps of their indoor areas through the use of small (easy to explore) replicas of such areas or through specific landmarks displayed in the areas may be hardly effective (Dodds et al. 1982; Lancioni et al. 2000, 2007; Papadopoulos et al. 2017; Parker 2009; Wright et al. 2010). In fact, the individuals may be unable to identify the replica's distinctive elements and/or recognize the corresponding elements in the real areas where travel has to occur, and thus fail to improve their orientation in such areas. Similarly, they may fail to search, find, or discriminate the

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landmarks displayed in the travel areas and consequently do not benefit from the presence of those landmarks (Lancioni et al. 2007; Zhu et al. 2019).

A way to alleviate severe spatial orientation problems and facilitate travel may involve the use of technology-aided strategies (Cuturi et al. 2016; Lancioni et al. 2007, 2010a; Ross and Kelly 2009). Most of the technology-aided strategies available were designed to help individuals with blindness and typical intellectual skills (Chebat et al. 2011; Gori et al. 2016; Kiuru et al. 2018; Lahav and Mioduser 2011; Legge et al. 2013). A few strategies also exist that were focused on helping people with visual and intellectual disabilities (Lancioni et al. 1995, 2010b, 2017, 2018; Parker 2009; Uslan et al. 1988). For example, Lancioni et al. (2017, 2018) used sound cues, such as verbal encouragements emitted by sound boxes or speakers located at target destinations, to help participants with severe/profound intellectual disabilities and blindness reach those destinations. The sound boxes or speakers, which were regulated by a computer or a smartphone, stopped producing those cues automatically once the participants reached the destinations.

Lancioni et al. (2010b) reported a study in which participants with intellectual disabilities and blindness were helped to orient to and enter rooms located on both sides of a long hallway. The participants carried with them a control unit, which (a) contained input keys that staff used to select the destination that the participants were to reach on each single travel occasion, (b) gave the participants the right direction, as they started to travel to the destination, and (c) called the participants' attention and verbally oriented them to enter the room/destination scheduled as soon as they reached it. This level of support was feasible because the participants' control unit was connected to frequency-coded radio devices and optic sensors located in the proximity of the room doors.

The results of both intervention strategies were quite positive indicating that they enabled the participants to independently reach the scheduled destinations and collect and transport objects in the process, thus making their travel meaningful. Notwithstanding the positive results, those strategies seem to present limitations that can curtail their usability. For example, the first strategy (i.e., use of sound cues emanating from the destination areas) may require the intensity of the cues to be relatively high so that the participant can hear them from his or her travel's starting point. Relatively loud cues can prove disturbing for other people sharing the same context and undermine the applicability/acceptability of the strategy. The second strategy relies on fairly sophisticated technology that needs to be installed in the setting in which the intervention takes place and may thus be relatively impractical and expensive.

In light of the above, developing an alternative strategy may be considered a practically relevant objective. The new strategy would need to (a) curb the drawbacks of each of the aforementioned strategies (i.e., reduce the level of disturbance and avoid sophisticated and expensive technology components) and (b) also suit individuals with relatively low levels of functioning. The present study was an effort to develop such a new intervention strategy and assess it with nine individuals with severe to profound intellectual disabilities and blindness (i.e., total blindness or minimal residual vision). Those individuals were to travel and transport objects to different rooms located on both sides of long hallways. The intervention strategy was based on the use of a smartphone and battery-powered light sources. The smartphone was programmed to verbally encourage the participant to walk forward, alongside a wall of the hallway, until its light sensor was activated by a light source positioned before a room/destination entrance. At that point, the smartphone encouraged the participant to stop his or her walking and enter the room. In an effort to limit the disturbance of the verbal cues, headphones or earpieces were introduced for seven participants (i.e., those who tolerated such devices) and a reduction of the cues' loudness was operated for the other two participants.

Method

Participants

Table 1 lists the nine participants using their pseudonyms and reports the participants' chronological ages and age equivalents for receptive communication and daily living skills (personal sub-domain) as measured on the second edition of the Vineland Adaptive Behavior Scales (Balboni et al. 2016;

Table 1 Participants' pseudonyms, chronological age, and Vineland age equivalents for Receptive Communication (RC) and Daily Living Skills: Personal Sub-domain (DLSP)

Participants (Pseudonyms)	Chronological Age (years)	Vineland age equivalents[1, 2]	
		RC	DLSP
Cliff	32	2;2	2;7
Grace	41	2;2	3;6
June	35	2;10	2;8
Ethel	47	2;5	3;6
Albert	42	1;11	3;3
George	45	2;0	3;3
Zoe	53	3;8	3;8
John	53	1;11	2;6
Martin	38	3;1	3;5

[1] The age equivalents are based on the Italian standardization of the Vineland scales (Balboni et al. 2016)

[2] The Vineland age equivalents are reported in years (number before the semicolon) and months (number after the semicolon)

Sparrow et al. 2005). The participants, who represented a convenience sample (Pedhazur and Schmelkin 1991), had chronological ages varying between 32 and 53 ($M = 43$) years. One of them was diagnosed with minimal residual vision (i.e., Martin); the other eight were diagnosed with total blindness. Their Vineland age equivalents ranged between close to 2 years and above 3.5 years for receptive communication, and between 2.5 years and above 3.5 years for daily living skills (personal sub-domain). Their levels of intellectual disability had been estimated (by the psychological services of the rehabilitation and care centers that they attended) to be in the severe to profound range.

The participants were included in the study based on a number of criteria set up after preliminary observations and staff consultations. First, they were able to ambulate without any physical assistance but, due to their orientation problems, even their indoor travel required staff supervision. The consequence of such dependence was that they spent large portions of their time in a sedentary position. Second, they could discriminate simple verbal instruction cues such as "walk," "stop," and "enter" and were thought likely to benefit from a systematic (and automatically arranged) use of those instruction cues to improve their indoor travel independent of staff assistance. Third, they were known to enjoy stimulation events, such as popular songs and staff attention (e.g., praise), so it was assumed that such events could be used at the end of the travel instances as incentives (reinforcers) to motivate their travel performance. Fourth, staff and families supported the intervention strategy used in this study (which had been described to them in advance), as they considered travel combined with object transportation beneficial for the participants.

Given their condition, the participants were unable to provide informed consent for their involvement in the study. Consequently, their legal representatives signed a consent form on their behalf. The study complied with the 1964 Helsinki declaration and its later amendments and was approved by a relevant Ethics Committee.

Procedure

Setting, Sessions, Research Assistants, and Stimuli Hallways of the care and rehabilitation centers that the participants attended served as setting for the study. Nine room entrances of each hallway were used as travel destinations. Those destinations were distributed on both sides of the hallway. Participants were typically involved in two sessions per day. A session included seven travels, each of which consisted of the participant reaching and entering a room/destination (and transporting an object on the way; see below). Research assistants with experience in carrying out technology-aided programs for persons with intellectual and multiple disabilities were in charge of the sessions, that is, managed the technology, led the participant to start each travel, used physical guidance in case of errors or breaks in performance, ensured stimulation at the end of each travel, and collected data.

A variety of stimuli including songs and other melodies, voices from staff and family members, and objects' noises were used at the end of each travel. The stimuli, which had been recommended by staff, were selected for the study following a preference screening procedure. This procedure involved the presentation of two or three 10-s segments of each of the stimuli exposed to the screening for at least 10 non-consecutive times over several assessment occasions (Hagopian et al. 2004; Lancioni et al. 2018). A stimulus was selected for use during the study if the participant had shown positive reactions (e.g., alertness, smiles, and vocalizations) during about or more than 50% of the presentations of its segments.

Smartphone-Based Technology The technology used for each participant during the intervention included a Samsung Galaxy J4 Plus smartphone with Android 9.0 operating system, which was (a) equipped with light sensor and Bluetooth v4.1, (b) fitted with the MacroDroid application and a variety of audio files, and (c) used in combination with Bluetooth headphones or earpieces and five battery-powered light sources. The audio files involved the verbal instruction cues "walk," "stop," and "enter" as well as the stimuli selected as preferred for the single participants and delivered to them at the end of each travel (e.g., songs and other melodies combined with voice recordings). The smartphone's display showed two symbols, one for each of the functions the research assistant in charge of the session was to operate, that is, "travel start" and "travel end." The MacroDroid served to program the functioning of the smartphone in line with the intervention conditions (see below).

Experimental Conditions The study was carried out according to a non-concurrent multiple baseline design across participants (Barlow et al. 2009). The baseline phase was followed by an intervention phase involving the use of the technology. The length of the baseline phase, which changed across participants (as required by the non-concurrent multiple design), was preset for each participant. Yet, extra sessions would be carried out if the participant's mean frequency of correct travels per session exceeded 3 and the frequency value of the last session exceeded the values of previous sessions (this condition never occurred). The research assistants who were in charge of the sessions (see Setting, Sessions, Research Assistants, and Stimuli) were provided with regular feedback on their performance by a study coordinator who had access to video recordings of those sessions. Feedback served to ensure procedural fidelity (Barnett et al. 2014). At the end of the study, interviews of staff personnel were carried out to determine their opinion about the smartphone-based intervention strategy.

Baseline Four to eight baseline sessions were carried out in the same hallways that also served for the intervention sessions. The technology was not available. At the start of each travel, the participant was (a) given an object (e.g., a bottle), (b) asked to find the room door on which the same object was hanging/displayed, and (c) accompanied to the departure point, along the hallway's wall he or she was to follow to reach the target destination/room. This strategy was adopted as it constituted the most common approach used by staff personnel in charge of the participants' daily programs. The room door displaying the same object as the one the participant was given could be the first, the second, or the third on the participant's way (i.e., along the hallway's wall the participant was to follow during the travel). The research assistant intervened with physical guidance to re-direct the participant if the participant entered a room preceding the destination, bypassed the destination, or had a break in performance of about 1 min. At each destination, the participant was helped to leave the object he or she had transported during the travel and was provided with 15–20 s of preferred stimulation (see Setting, Sessions, Research Assistants, and Stimuli).

Intervention During the 80 to 100 intervention sessions, the technology was in use. The upper section of Fig. 1 provides a schematic representation of a hallway with nine room entrances. The representation also includes five light sources placed before the entrances of rooms constituting the session destinations. Different rooms could serve as destinations in different sessions. Given the positions of the light sources shown in Fig. 1, the seven travels for the participant could be as follows: (i) from Start A to room 2, (ii) from the outside of room 2 to room 3, (iii) from the outside of room 3 to room 5, (iv) from start B to room 6, (v) from the outside of room 6 to room 9, (vi) from start A to room 2, and (vii) from the outside of room 2 to room 3. The lower section of Fig. 1 provides a schematic representation of how the participant wore the smartphone (i.e., fixed at his or her ankle) to ensure that the smartphone's light sensor would be activated by the light source placed before the entrance of the destination room.

At the start of a travel, the research assistant (a) gave the participant an object that was to be transported to the destination (i.e., as in baseline), (b) accompanied the participant to the travel's starting point (i.e., alongside the hallway's wall on which the destination was located), and (c) touched the "travel start" symbol on the smartphone's display (see Smartphone-based Technology). Following the last action, the smartphone began to emit the instruction cue "walk" at intervals of 1–2 s. This cue continued to be presented until the participant reached the light source available before the entrance of the destination room. The light source activated the smartphone's light sensor and caused the smartphone to present the instruction cue "stop" (once or twice) and thereafter the cue "enter." The cue "enter" was presented in the same way as "walk." When the participant entered the room, the research assistant (a) touched the "travel end" symbol on the smartphone and (b) took the object the participant had transported while praising the participant. Touching the "travel end" symbol halted the instruction cues and started the delivery of 15–20 s of preferred stimulation. Physical guidance by the research assistant was available as in baseline.

After the initial 12 to 22 intervention sessions (i.e., once the participants' travel performance had improved), efforts were made to eliminate or curb the environmental disturbance caused by the cues. Specifically, Bluetooth headphones or earpieces were introduced for the seven participants who tolerated those devices (i.e., Ethel, Grace, George, June, Carole, Albert, and Martin) and a reduction in the loudness of the cues was gradually operated for the other two participants (i.e., John and Cliff). For these two participants, the intensity of the cues, as perceived at 1-m distance, was reduced to about 65 dB and 55 dB, respectively.

Interviews of Staff Personnel Interviews were carried out with 54 staff persons (e.g., teachers and physiotherapists) who worked in rehabilitation and care centers for people with severe, profound, and multiple disabilities and were familiar with intervention strategies available for these people. The 54 staff persons were not directly connected with the participants of this study, represented a convenience sample (Pedhazur and Schmelkin 1991), and included 47 women and 7 men whose ages ranged between 29 and 58 ($M = 40$) years. They were divided into nine groups of six members. The members of each group read a brief description of the intervention strategy and then saw a video including three travels of one participant wearing headphones/earpieces or being exposed to cues of reduced intensity. The travels were directed at reaching the first, second, and third room/destination on the participant's way (i.e., with the order of the destinations changing across participants). While watching the first travel, staff received information as to the verbal cues (i.e., "walk," "stop," and "enter") the participant was receiving at the different stages of the travel. After watching all three travels, staff scored the intervention strategy on four specific questions. Scores could range from 1 to 5 (with 5 being the most positive score). The four questions were as follows: (1) How much do you think the strategy can help the participant travel successfully?, (2) How much do you think the participant is comfortable in using the strategy for his or her travel?, (3) How much do you think the strategy could be used in daily contexts?, and (4) How much do you like (recommend) the strategy?

Measures

Recording concerned (a) the participants' travels to the room destinations and whether those travels were correct and (b) the distance (number of meters) covered by the session's travels.

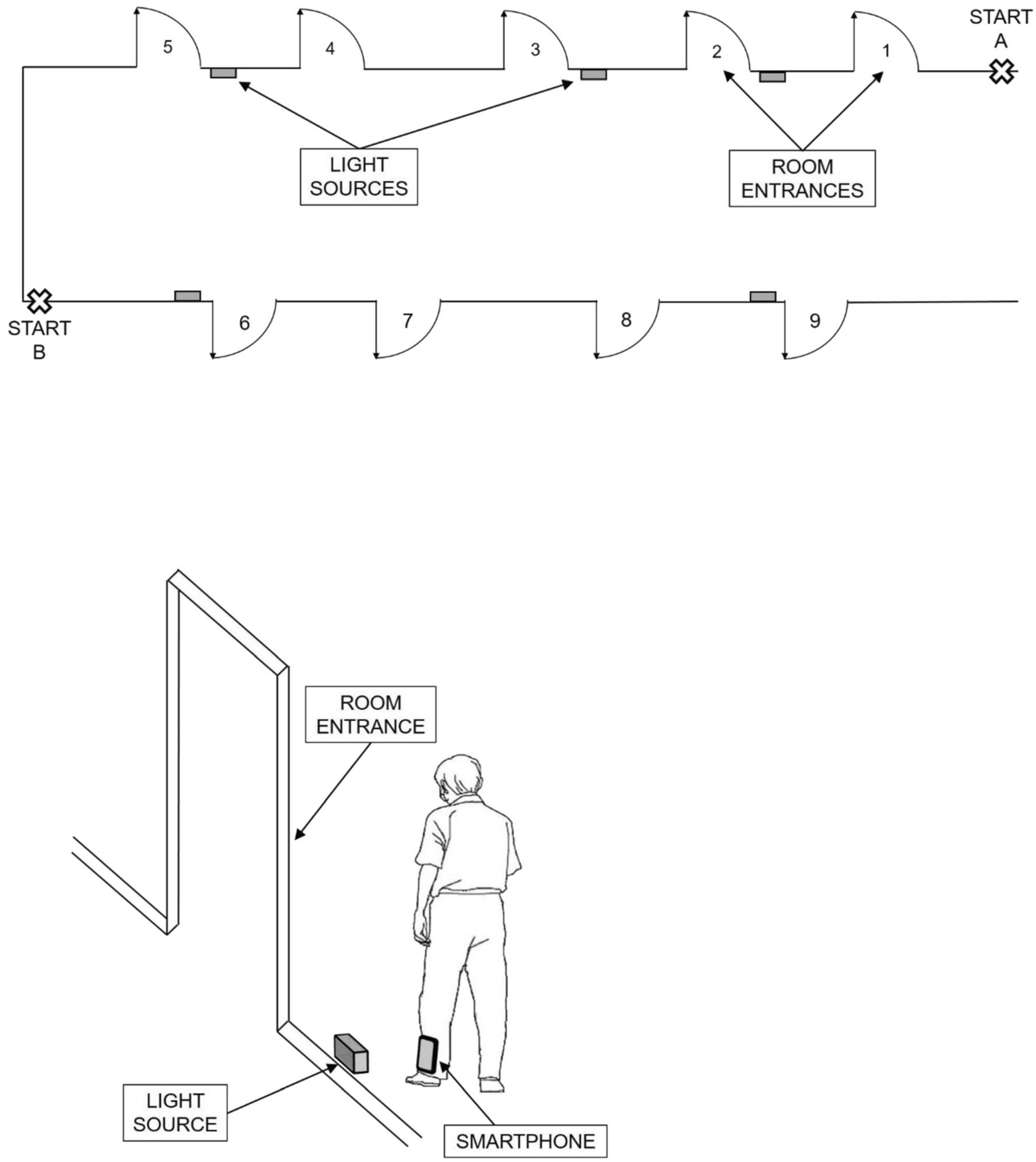

Fig. 1 The upper section of the figure provides a schematic representation of a hallway with nine room entrances. The representation also includes five light sources placed before the room entrances constituting the session destinations. The lower section of the figure provides a schematic representation of (**a**) how the participant wore the smartphone and (**b**) where the light source was displayed to activate the smartphone's light sensor as the participant approached the entrance of the destination room

A correct travel was recorded if the participant reached the room entrance targeted as destination and entered the room independent of research assistant's physical guidance. Such guidance would occur to direct the participant if he or she (a) entered a wrong room (i.e., a room, which was between his or her starting point and the target destination), (b) bypassed the entrance of the room targeted as destination, or (c) had a break in the travel performance of about 1 min. The distance covered by a session's travels was the sum of the single travels' lengths. Those lengths were already known (i.e., had been verified in advance). Inter-rater agreement on the travels and distance covered was assessed in more than 20% of the sessions of each participant with a reliability observer collecting data together with the research assistant in charge of the sessions. The percentages of inter-rater agreement on travels (computed on the single sessions by dividing the number of travels for which both raters reported the same correct or incorrect score by the total number of travels and multiplying by 100%) were between 86 and 100, with means exceeding 98 for all participants. The percentages of agreement on the distance covered (computed by dividing the number of sessions in which the raters reported the same distance by the total number of sessions with two raters and multiplied by 100%) were above 94 for all participants.

Data Analyses

The baseline and intervention travel data of every participant were summarized as mean frequencies of correct travels per session over blocks of sessions and reported in graphic form. To determine whether the differences between those two sets of data were statistically significant, the Kolmogorov-Smirnov test (Siegel and Castellan 1988) was used for each of the nine participants.

Results

The nine panels of Fig. 2 summarize the participants' baseline and intervention travel data. Specifically, each panel reports the mean frequency of correct travels per session over a block of sessions for one of the participants. The blocks include two sessions during the baseline and five sessions during the intervention. Blocks with a different number of sessions (i.e., at the end of the intervention phase) are marked by a numeral that indicates how many sessions they include.

During the baseline, the participants' mean frequencies of correct travels per session varied between zero (June and Albert) and slightly above 2 (Zoe). During the intervention phase, with the smartphone-based cues, all participants displayed a great improvement of their travel performance. In fact, their mean frequencies of correct travels per session during the last 45 sessions of the phase reached values ranging between about 6.5 (John) and 7 or near 7 (the others). The Kolmogorov-Smirnov test confirmed that the difference between baseline and intervention frequencies was statistically significant ($p < 0.001$) for each participant. The mean distance covered by the session's travels varied between about 50 m (June and Zoe) and over 80 m (Ethel).

Table 2 shows the staff personnel's mean scores and score ranges for each of the four interview questions on the intervention strategy. The mean scores for those questions were 4.17, 4.00, 3.48, and 4.09, respectively. That is, the staff's view was that the strategy could largely help the participant travel successfully and the participant was very comfortable in using the strategy. Staff also expressed clear liking of (willingness to recommend) the strategy. With regard to the usability of the strategy in daily contexts, staff were somewhat more cautious, reporting a mean score of 3.48. Their ratings were mostly divided between 3 and 4 (indicating that their view of the strategy's usability was between moderate/reasonable and large).

Discussion

The results of the study indicate that an intervention strategy relying on the use of a smartphone automated via MacroDroid and light sources was helpful in improving independent indoor travel in people with severe to profound intellectual disabilities and blindness. All nine participants managed to reach the travel destinations with a high level of accuracy, and staff interviewed about the intervention strategy seemed to be fairly positive about it. In light of these results, a number of considerations may be put forward.

First, the successful travel performance (combined with object transportation) observed during the intervention sessions represents a relevant progress over the participants' baseline functioning. This progress can be directly related to (a) the suitability of the automated smartphone for providing relevant travel cues and changing those cues at the appropriate time (i.e., in relation to light sources), (b) the effectiveness of those cues in guiding the participants' travel performance, and (c) the participants' motivation to follow those cues throughout the scheduled travels (Kazdin 2012; Pierce and Cheney 2008).

Second, relying on simple technology such as a smartphone and light sources for supporting the participants' travel performance can be considered relevant for two main reasons. One reason is that such technology is easy to set up and use as well as fairly inexpensive and affordable (Scherer et al. 2018; Smith et al. 2018). The other reason is that the technology (a) can be used with no disturbance, or only relatively minor disturbance, for other individuals sharing the contexts with the participants, and thus (b) cannot raise serious objections against its application in those contexts (Borg 2019).

Third, the verbal travel cues used in this study would not be applicable without technology support. In fact, staff would find it impossible to directly present those cues in terms of time costs and also in terms of energy. Moreover, staff's direct inputs during travel would make the participants look very dependent with negative implications for their overall achievement and social image (Vornholt et al. 2013). The lasting impact of the cues over the intervention phase (which was reflected by the participants' consistent responding throughout the phase) was presumably related to the stimulation available after the single travels (Kazdin 2012; Pierce and Cheney 2008). With regard to this point, it might be relevant to recall that such stimulation was selected based on participants' preference (Hagopian et al. 2004; Lancioni et al. 2018).

Fourth, this study was mainly focused on investigating the viability of the strategy. Thus, research assistants were involved in carrying out the study and, in the process, replaced regular staff in charge of the rehabilitation and care of the participants. One should ensure that in future research regular

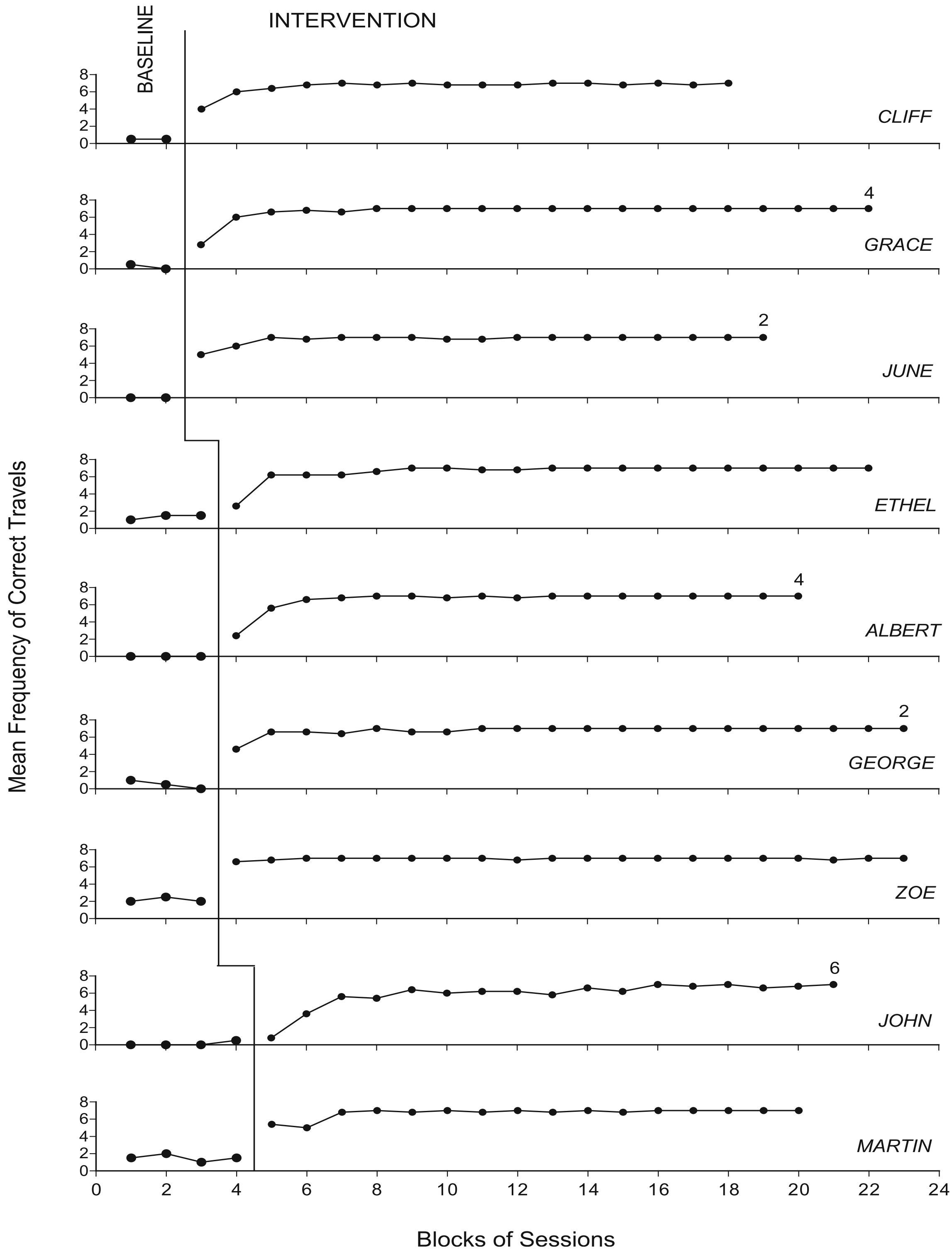

Fig. 2 Each panel reports the mean frequency of correct travels per session over a block of sessions for one of the participants. The blocks include two sessions during baseline and five sessions during the intervention. Exception blocks (at the end of the intervention phase) are marked by a numeral indicating the number of sessions they include

staff take full responsibility for the implementation of the intervention strategy (Kazdin 2011). Direct staff responsibility would increase the likelihood of the strategy being used after the research period.

Fifth, the ratings of the strategy provided by the staff personnel interviewed at the end of the study seem to be an acknowledgment of (a) the beneficial effects of the strategy for the participants' performance and (b) the participants'

Table 2 Mean scores and score ranges on the questions used for staff interviews

Questions	Mean scores	Score ranges
1	4.17	3–5
2	4.00	3–5
3	3.48	2–5
4	4.09	3–5

Scores could vary from 1 to 5 (with 5 being the most positive score)

comfortableness in using the strategy (Brown et al. 2013; Elsman et al. 2019). The staff ratings may also suggest the need of exploring new ways to set up the strategy in daily contexts so as make it largely acceptable and convenient to use in those contexts (Luiselli et al. 2010).

Limitations

Two main limitations of the study may be mentioned here. The first limitation is concerned with the number of participants included in the study. Although the data were relatively solid, successful replication efforts would be required before one can make definite statements about the overall robustness of the strategy reported and its implications (Brandt et al. 2014; Kazdin 2011). A second limitation concerns the fact that only one particular type of setting was used. It would be practically relevant to (a) assess how the technology employed in this study can be adapted to different types of settings and (b) consequently determine how readily the strategy can be applied across contexts (Kazdin 2011; Makel and Plucker 2014).

In conclusion, the results of this study are encouraging as to the potential of a simple, smartphone-based intervention strategy for helping participants with severe/profound intellectual disability and blindness in their indoor travel. New research will need to address the main limitations of this study and verify the feasibility of conducting the study with regular staff personnel taking responsibility for the sessions. New research may also investigate additional technology-aided solutions that could constitute functional alternatives to the present smartphone-based strategy for participants with different needs and/or in different contexts.

Authors' Contributions GL was responsible for setting up the study, acquiring and analyzing the data, and writing the manuscript. MO, JS, LD, GA, VC, and AN collaborated in setting up the study and/or analyzing the data and writing/editing the manuscript.

Compliance with Ethical Standards

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

Ethical Approval Approval for the study was obtained from the Ethics Committee of the Lega F. D'Oro, Osimo, Italy. All procedures performed were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Informed Consent Written informed consent for the participants' involvement in the study was obtained from their legal representatives.

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