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MultiTab: A Novel Portable Device to Evaluate Multisensory Skills*

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***Abstract*— To infer spatial-temporal features of an external event we are guided by multisensory cues, with intensive research showing an enhancement in the perception when information coming from different sensory modalities are integrated. In this scenario, the motor system seems to also have an important role in boosting perception. With the present work, we introduce and validate a novel portable technology, named MultiTab, which is able to provide auditory and visual stimulation, as well as to measure the user's manual responses. Our preliminary results indicate that MultiTab reliably induces multisensory integration in a spatial localization task, shown by significantly reduced manual response times in the localization of audiovisual stimuli compared to unisensory stimuli**

***Clinical relevance*— The current work presents a novel portable device that could contribute to the clinical evaluation of multisensory processing as well as spatial perception. In addition, by promoting and recording manual actions, MultiTab could be especially suitable for the design of rehabilitative protocols using multisensory motor training.**

I. INTRODUCTION

In daily life, we are exposed to multisensory cues that our brain integrates to create a coherent representation of the world [1]. It is intensely studied how perception can be boosted in the presence of multisensory stimuli (e.g., shorter reaction times, more precise and accurate encoding), compared to when only unisensory stimulation is provided [1], [2]. The two principles that have been suggested as a driven for multisensory integration are spatial [3], [4], and temporal congruency [5], [6]. For example, when a light and a sound are originated in a temporal and spatial binding window (i.e., close in time and location), it is likely that both stimuli will be integrated into a unified percept [7]. Multisensory cues can be particularly used to infer spatio-temporal features of an external event. For what concerns spatial representation, past literature showed that the ability to localize a sound is improved if the auditory stimulus is accompanied by a visual input, congruent in space and time [8]–[10]. Thus, multisensory mechanisms can facilitate sensory information processing by producing a multisensory response enhancement (MRE; [6]). Motor responses are one of the tools employed to evaluate spatial perception. For instance, by pointing towards a sensory source (either a sound or a flash) in the space, a person translates into motor coordinates the spatial representation of the perceived stimulus [11], [12]. However, motor action is not simply a measure of perception, as both processes are tightly coupled being both influenced by each other. It has been suggested that multisensory integration and motor system lead to enhanced sensory processing [7]. In this line, Valzolgher and collaborators (2020) suggested that, when updating auditory spatial localization, kinesthetic cues have an added value to just paying attention to seeing and/or hearing sounds' positions [13].

Within this framework, the present work introduces and validates a novel technological system, named MultiTab. This device was conceived as an easily portable system that provides spatialized auditory and visual stimulation to investigate multisensory spatial skills. In addition, MultiTab promotes and measures motor actions performed by the user during experimental tasks, without the need for complex systems for the recording of manual responses. Thanks to this design, MultiTab can provide multiple advantages in a clinical context. One possible application could be contributing to the rehabilitation of post-stroke patients, who are affected by motor, cognitive, and/or multisensory integration dysfunctions, that could lead to body representation alterations [14]. In this context, MultiTab could be implemented as an assessment tool for multisensory processing and spatio-temporal unisensory and multisensory perception. Moreover, MultiTab could be also valuable in the design of rehabilitation protocols, which involve motor responses that boost the attentional resources played by the patients in multisensory training.

Here, we present the validation of MultiTab in a spatial localization task, in which we measured the Response Times (RTs) in 8 healthy adults in unisensory and multisensory conditions. We expected MultiTab to be able to provide audiovisual stimulation within a reliable space and time binding window, yielding shorter RTs when both audio and visual cues were available.

II. METHOD

A. MultiTab System

MultiTab (Fig. 1) consists of two identical modules (tab A and B), each equipped with 64 touch sensors (capacitive

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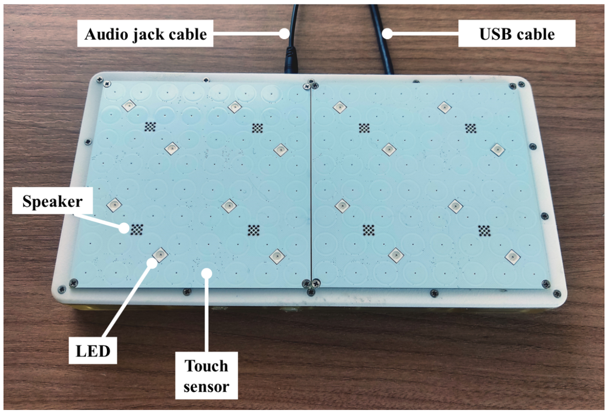

Fig. 1. MultiTab system. Between the two modules, the device comprises 128 touch sensors, 16 LEDs, 8 speakers, a USB cable, and an audio jack cable.

sensors), eight Red Green Blue (RGB) light-emitting diodes (LEDs), and four speakers (mod ASE02008MR-LW150-R). The modules are integrated into an external support structure. The mechanical design of the device was carried out using PTC Creo Parametric 7.0, a parametric 3D CAD platform, and optimized for simplicity in construction and ease of future design iterations. All components were fabricated using Additive Manufacturing (AM), specifically Selective Laser Sintering (SLS) on a 3D System ProX SLS 6100 machine. The custom components were manufactured using Duraform Polyamide 12 (Nylon), a thermoplastic with desirable mechanical properties and fine-feature surface resolution. The material is suitable for real-world functional testing and low to mid-volume production runs and is capable of meeting UPS Class VI standards. The use of AM allowed for cost and time savings in development, making design iterations more feasible. The final design, as shown in Fig. 2, encompasses the overall structure, integrated electronics, and two modules that provide audiovisual stimulation and sensing.

The flow of information with the PC took place through a USB port with a serial line RS232. There are three microcontrollers, one on each tab, and the third one manages communications with the remote PC. This microcontroller, an ATSAMD21G18P embedded in the Seeeduino XIAO module in tab A, converts the signal into a serial line RS485. There is a SN65HVD24D to manage the RS485 line with the 2 tabs of the MultiTab, modified via flex cable and connected by flat cable to tab B (see Fig. 3 for the block scheme).

MultiTab allows the serial reproduction of spatialized sounds and lights within user-defined temporal limits. Moreover, the device permits registering the position of the touch with a 1.5-by-1.5 cm precision. Reproduction of the auditory and visual stimuli and recording of the touch by the touch sensors are carried out in Matlab (Matlab 2019b, the Mathworks). The flow of information between Matlab and MultiTab takes place through a USB port by sending commands suitably formatted on the RS232 serial line 250000 baud, 8 bit, parity N, coming from a remote PC. The PC USB port also provides the necessary power supply for the operation of the system. Each command consists of:

- 1 starting byte
- 1 peripheral address byte
- 1 unit address byte
- 1 command byte
- 3 bytes identifying any parameters of each command
- 1 ending byte

B. Technical Validation

To test the accuracy and precision of MultiTab in playing sounds and lights, we measured auditory and visual stimulation through the Biosemi ActiveTwo System. From each unit (amplifier or LED) of MultiTab, auditory (70 dB pink noise, 100 ms) and visual stimuli (2.8 cd blue light, 100 ms) were recorded through a wired PGA58 vocal microphone and a photodiode, respectively. The two sensors were connected to two different channels of the Biosemi system. 100 auditory and 100 visual stimuli per unit were recorded during unisensory (auditory or visual) and multisensory (audiovisual) reproductions, separately. To evaluate the stimuli reproduction's accuracy and precision, the measured traces were compared with their supposed onset, offset, and duration (100 ms) of stimulation. Specifically, the mean and standard deviation (SD) of the recorded onset, offset, and duration

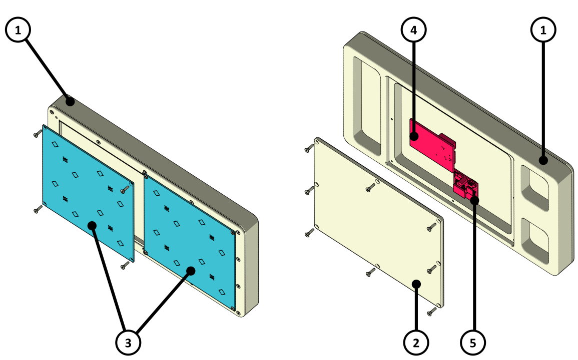

Fig. 2. CAD view of the device. 1) outer shell; 2) cover plate; 3) electronic tabs; 4) Seeee XIAO microcontroller; 5) service board.

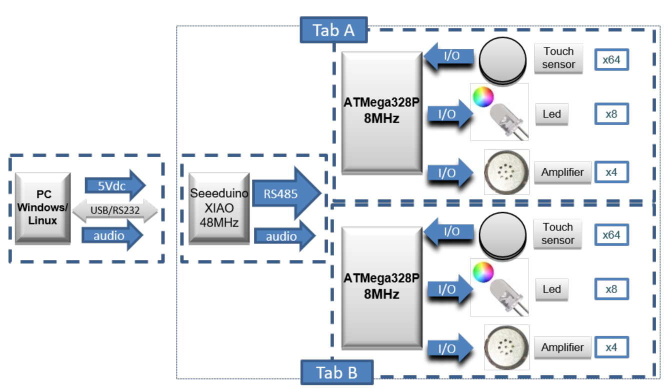

Fig. 3. MultiTab block scheme.

were calculated as a measure of the stimuli's production accuracy and precision, respectively. For the audiovisual stimuli, graphical inspection and statistical comparison of the onset and offset of auditory and visual traces ensured the simultaneity of the two sensory stimulation.

C. Experimental Validation

8 participants (mean ± Standard Deviation (SD) age: 28.37 ± 3.02 years old) took part in the experimental validation of MultiTab, after giving written consent in accordance with the local Ethics committee (ASL3 Genovese) and the declaration of Helsinki. To evaluate whether spatial multisensory skills can be tested using MultiTab, we asked participants to perform a spatial localization task. Participants rested their heads on a chinrest placed at 36 cm from MultiTab which presented spatialized stimuli. In three separate conditions, counterbalanced across participants in different blocks, the stimuli to localize were auditory (pink noise, 100 ms), visual (blue light, 100 ms), or audiovisual (the pink noise and the blue light played simultaneously for 100 ms). Audiovisual stimulation (reproduced by a speaker and one of the two LEDs in proximity) was perceived by participants as coming from the same source. To likely equalize the localization of the visual stimuli to that of auditory stimuli, we degraded the former by blurring the participant's vision through specially designed sunglasses. In separate blocks, stimuli could be reproduced either on the left or right side of the device (i.e., tab A or B) and participants were informed accordingly. In each trial, participants started with their dominant-hand index placed on a starting point (i.e., a marked point on the bottom of the device) and were instructed to manually localize the stimuli by tapping the top surface of MultiTab at the position they perceived the stimuli. We asked participants to respond as fast and as accurately as possible (and, in any case, no later than 1.5 s).

Touch sensors of MultiTab recorded the subjects' touch on the surface. Each participant localized a total of 80 auditory stimuli (8 positions repeated 10 times each), 160 visual stimuli (16 positions repeated 10 times each), and 160 audiovisual stimuli (16 positions repeated 10 times each). For each participant, RT per trial, i.e., the time between the start of the stimulus and the first touch detected by the device, was measured. To investigate participants' MRE in the spatial localization task, we compared the participants' median RTs between the auditory, visual, and audiovisual condition by running a one-way ANOVA with Condition as a within-subject factor with three levels (auditory-only, visual-only, and audiovisual). Moreover, to investigate the magnitude of the multisensory gain, for each participant we calculated the absolute amount of MRE as follows [6]:

$$MRE = min[median(RT_{audio}), median(RT_{visual})] - median(RT_{audiovisual}) \quad (1)$$

Thus, we statistically compared the average absolute MREs against zero to detect significant multisensory gain. All statistical analyses were carried out in MATLAB (MATLAB R2019b, MathWorks) and R (4.1.1. version; [15]).

III. RESULTS AND DISCUSSION

A. Technical Validation

Technical validation of MultiTab checked the stimuli production's accuracy and precision, specifically of onset, offset, and duration of the auditory and visual stimulation (unisensory and multisensory). The visual stimuli were precise in the onset and offset of the reproduction (i.e., the difference between the actual and the supposed beginning or end of the stimulation), while the acoustic stimuli resulted do be less precise in the onset of the reproduction (Audio: mean onset: 4.15ms; SD onset: 1.87ms; mean offset: -1.38ms; SD offset: 1.68ms; Visual: mean onset: 0.24ms; SD onset: 0.56ms; mean offset: -1.23; SD offset: 1.80ms). For all the sensory stimulation (i.e., the visual and auditory stimuli from all the units of MultiTab), the recorded mean stimulus duration matched the theoretical one (100 ms), with negligible variation between multiple recordings from the same unit (Audio: mean: 96.25ms; SD: 1.85ms; Visual: mean: 99.69ms; SD: 1.78ms; Audio-visual: mean visual: 98.06ms; SD visual: 0.48ms; mean audio: 98.21ms; SD audio: 2.56ms). For the audiovisual condition, we checked the simultaneity of the stimulation between the auditory and the visual inputs through a graphical inspection of the multisensory traces (an example in Fig. 4a). Fig. 4b shows that the differences in the onset and offset of reproduction between the two stimuli were not substantial. Overall, technical validation of MultiTab suggests that the device is an accurate and precise tool to provide multisensory spatialized inputs.

B. Experimental Validation

MultiTab was used to test participants' multisensory spatial skills. After assessing that data followed a normal distribution (Shapiro-Wilk test; auditory: W = 0.95, p = 0.726; visual: W = 0.97, p = 0.920; audiovisual: W = 0.96, p = 0.865), we compared participants' median RTs during unisensory (visual or auditory) and multisensory (audiovisual) conditions. Preliminary data showed a significant difference among the three conditions in the median RTs of participants localizing stimuli on MultiTab (Fig. 5; $F_{(2,14)} = 28.24$, $p \leq 0.001$). Specifically, post-hoc two-tailed t-tests (after Bonferroni correction for multiple comparisons) revealed that participants were significantly faster in localizing

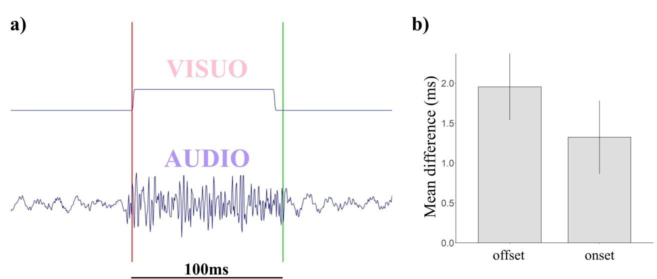

Fig. 4. Simultaneity of the auditory and visual stimulation during the audiovisual condition. a) Example of visual (upper) and auditory (lower) recordings' traces of 100ms temporal interval. b) Mean difference in the onset and offset of the stimulation between the auditory and the visual inputs during the audiovisual condition.

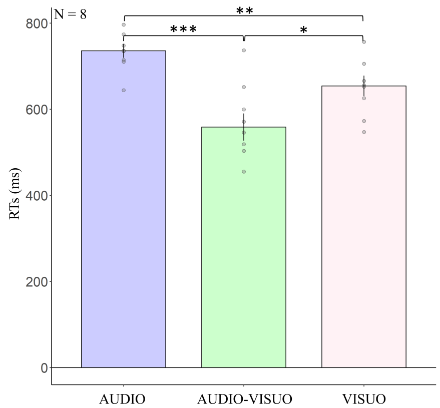

Fig. 5. Median RTs during the spatial localization task, for the auditory, visual, and audiovisual conditions. Error bars show standard errors. * $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$.

audiovisual stimuli than visual-only ($t_{(7)}$ = -3.85, p = 0.018) or auditory-only ($t_{(7)}$ = 6.09, p = 0.001) stimuli. Statistical analysis also showed a significant difference between the performance in the auditory and visual conditions, with shorter median RTs in the localization of visual inputs ($t_{(7)}$ = 4.94, p = 0.004). This last result is in line with previous works showing a greater precision of the visual system in processing spatial information compared to other sensory modalities [1].

This primacy of vision in spatial perception may imply that participants of the present study preferentially responded to the visual inputs even when localizing audiovisual stimuli. To rule out this possibility, we calculated the absolute amount of MRE [6], which indicated the multisensory gain with respect to the faster unisensory condition that, for most of the participants, was the visual condition. Participants showed mean multisensory gains that were normally distributed (Shapiro-Wilk test: W = 0.96, p = 0.830) and significantly different from zero (MRE mean ± SD: 74.95 ms ± 19.41 ms; $t_{(7)}$ = 3.85, p = 0.006), suggesting that the observed MRE was the result of multisensory processing and not of participants preferentially responding to visual inputs. Taken together, these preliminary results showed multisensory facilitation effects in localizing spatialized stimuli with MultiTab, which are in line with the multisensory enhancement found in previous studies investigating spatial skills [8]–[10]. From the technical and experimental validation of MultiTab, we demonstrated the device's reliability in the investigation of multisensory spatial skills, suggesting the use of MultiTab as a more portable alternative than the canonical experimental methods.

IV. CONCLUSIONS

With this work, we present a preliminary validation of a new multisensory technology, MultiTab, in 8 healthy adults. This portable device allowed us to present auditory and visual stimulation in a spatial localization task and measure the RTs of the participants by recording their manual responses on the device's top surface (i.e., tapping). The reduction in the RTs in the multisensory audiovisual condition indicated that MultiTab reliably provides both stimuli in a temporal and spatial binding window, allowing multisensory processing to occur. By providing multisensory information and allowing easy recording of users' manual responses, MultiTab is a promising technology that may have relevant contributions in the clinical field, facilitating evaluation and multisensory rehabilitation training.

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