# The Augmented Movement Platform For Embodied Learning (AMPEL): development and reliability

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**Abstract**

Background. Balance and gait impairments are highly prevalent in the neurological population. Although current rehabilitation strategies focus on motor learning principles, it is of interest to expand into embodied sensori-motor learning; that is learning through a continuous interaction between the cognition and the motor system, within an enriched sensory environment. Current developments in engineering allow for the development of enriched sensory environments through interactive feedback.

Methodology. The Augmented Movement Platform for Embodied Learning (AMPEL) was developed, both in terms of hardware and software by an inter-disciplinary circular participatory design strategy. The developed device was then tested for in-between session reliability for the outcome measures inter-step interval and total onset time was investigated. Ten healthy participants walked in four experimental paths on the device in two different sessions, and between session correlations were calculated.

Results. AMPEL was developed both in terms of software and hardware, with three Plug-In systems (auditory, visual, auditory + visual). The auditory Plug-In allows for flexible application of augmented feedback. The in-between session reliability of the outcomes measured by the system were between high and very high on all 4 walked paths, tested on ten healthy participants [mean age 41.8 ± 18.5; BMI 24.8 ± 6.1].

Conclusion. AMPEL shows full functionality, and has shown between session reliability for the measures of inter-step-intervals and total-onset-time in healthy controls during walking on different paths.

Keywords.
Embodied environment, technology, augmented feedback, participatory design strategy, Plug-in System, auditory and visual feedback

## Introduction

Learning is an essential part of life. Learning can be defined as an ongoing process of acquiring new skill sets and knowledge through different modalities and experiences. More specifically, motor learning has been described as a 'practice or experience leading to a relatively permanent change in the capability for skilled behaviour'(1). From infancy to adulthood, motor learning enables us to obtain the skill sets necessary for activities of daily living, either in terms of finer motor movements such as handling cutlery, tying a shoe lace, or in terms of grosser motor movements such as walking, jumping or running. The understanding of motor learning; and its principles(2) is essential when acquiring more complex movement patterns, for example, those needed for skill acquisition in sports performance(3). The principles of motor learning also becomes essential when re-learning and refining motor skills due to neurological assault(4).

However, how do we re-learn or train motor skills that are affected by neurological degeneration? We believe that classical approaches in physiotherapy can profit from new insights in embodied interaction(5, 6), where reinforcement learning through biofeedback in which enriched sensory environments is explored(7). Accordingly, body movements associated with sounds invoke the reward system and an associated incentive for adaptation and learning(8-10).

With the intension of expanding the classical motor learning theories within the framework of embodied interaction, targeted specifically for the neurological population, we developed the Augmented Movement Platform for Embodied Learning (AMPEL). The type of learning we thereby envision is here called: interactive embodied learning. We assume that it is based on a continuous interactive interplay between the cognitive and motor systems within the learner, regardless of the task that is being learnt. Interactive embodied learning occurs when a new cognitively challenging task is learnt and produced through movement, while interacting with an environment, in such a way that what is first cognized (e.g., a movement sequence in association with responses from the environment) becomes facilitated in the sense that less cognitive effort is needed (e.g., to execute the movement sequence with the assistance of responses from the environment). Interactive embodied learning has mostly been applied in the context of learning and education (11). In a study investigating embodied learning of children in a classroom, significant improvements were found in the children's cognitive abilities and academic performance(12). However, interactive embodied learning has yet to be investigated in contexts other than education; for example, in the context of re-learning movement behaviour, such as needed in neurological rehabilitation.

In order to initiate the desired research on interactive embodied learning, we developed AMPEL with an inter-disciplinary team of engineers, technicians, musicologists and rehabilitation experts. We used a circular participatory design strategy(13) to develop AMPEL. With this strategy, the development of AMPEL followed a dynamic and interactive reviewing process of each developmental milestone by the inter-disciplinary team. This strategy allowed for change and adaptation to be made during development, in order to optimise the final developed prototype, which had two purposes in mind.

The first purpose was to create an environment that would offer a human-device interaction with auditory or other forms of feedback. Within an embodied task, auditory feedback can be used as an error-correcting mechanism such as in sports performance(14) and stroke rehabilitation(5, 15). In addition, auditory feedback can be given a particular structure or narrative, like in a melody. Association of melody components (e.g., notes) with movement components (e.g., steps or turning) may be beneficial for learning movement sequences, especially when the melodic components are predictive. When movement components can be associated with melodic components, then the learning of movement components may be facilitated on the basis of the (predictive) melodic narrative.

The second purpose for developing AMPEL was to perform experimental designs in the context of embodiment with grosser motor tasks such as walking or stepping, within a future perspective of functional neurological rehabilitation. In the neurological population, it is significant to train these grosser motor tasks with the emphasis on dynamic balance, as these impairments are highly prevalent in this population, with the consequence of an increased risk of falls(16). Furthermore, evidence has confirmed the requirement of cognitive functions for balance and gait control(17). Therefore, creating an embodied environment where these components are presented simultaneously is highly desirable.

It is also true that some commercial devices, such as interactive floors (Lumo Play, Lumo Interactive Inc.(18)) exist. Yet these commercially available devices are often designed and developed for gaming purposes. Moreover, they do not allow for flexibility in investigating embodied learning; imposing challenges in regards to collection of reliable raw data during movement. On the contrary, with AMPEL, information of both the cognitive performance as well as the movement behaviour of each step (such as inter-step-intervals total-tile-onset-time) can be logged simultaneously, allowing for understanding interactive embodied learning. Therefore, objective measures can be logged and used to investigate dynamic balance, an advantage over the current outcome measures for dynamic balance used in current rehabilitation settings, such as the Borg Balance Scale (a subjective observational scoring system)(19-21).

The additional value of developing AMPEL is that it offers a tool to further research the effectiveness of interactive embodied learning with the paradigm of sensory-motor learning strategies applied to rehabilitation. Thus, we wanted to develop a platform where different feedback modes could be used, with flexibility in mind, which is the main reason for using an adaptable 'Plug-In' system with auditory and visual plug-ins.

Our auditory Plug-In allows a distinction between music (a simple melody with different pitches associated to specific tiles) and sound (a buzz, a single pitch associated to all tiles), broadening investigations when applying auditory feedback. This is of interest in neurological rehabilitation, as music-based interventions have shown to yield promising results on cognitive and motor functions in the neurological population(22). Taken together with the motivational and rewarding qualities of music towards motor learning(23) and the neurophysiological effects of engaging in a sensori-motor task(24, 25), this system opens up possibilities for various research designs with possible end goals of developing novel embodied sensori-motor rehabilitation strategies.

In this paper, we describe the hardware and software functionality developments of AMPEL, as well as provide reliability data of measurements obtained from AMPEL collected in healthy controls.

## Method

The methods are divided into two parts; the first part describes the methodology of developing AMPEL, and the second part describes the methodology of analysing technical reliability of motor performance parameters as inter-step-intervals and total-onset-time measurements obtained from AMPEL.

### PART 1. Developing AMPEL

*The Hardware*

The AMPEL system consists of 21 interactive floor tiles. Each tile has a custom made printed circuit board (PCB), which is covered with a translucent acrylic glass plate The PCB is equipped with 40 RGB LEDs and 4 force sensitive resistors (FSR). These FSR sensors detect whether pressure is applied to the tile or not. A microcontroller is used to read out the FSR sensor values, to control the LED colours and to handle the data communication. The ATmega328p microcontroller is selected in order to make the system compatible with the Arduino Uno architecture.

The FSR sensors are constructed with Velostat as a pressure sensitive conductive sheet. Velostat is a polymeric foil impregnated with carbon black to make it electrically conductive and is in general used as a packaging material. When pressure is applied to the Velostat material its resistance drops. By measuring this resistance change, it is possible to detect if someone is on the tile or not. The Velostat is attached to interdigitated electrodes at the bottom of the PCB. This way a variable resistor is created, which is connected in series with a fixed resistor to make a voltage divider. The resulting variable output voltage of the voltage divider is measured with an analogue to digital converter on the microcontroller.

The RGB LEDs are all connected together so that they light up with the same colour. The connection scheme is the same as the one used in 12V RGB LED strips: groups of three LEDs in series with a current limiting resistor and the different groups connected together in parallel. Three pulse width modulation (PWM) outputs of the microcontroller are used to obtain colour mixing of the red, green and blue LEDs. For each colour an N-channel MOSFET is used as a switch.

A supply voltage of 12V is used to power the LEDs in the tiles. An on-board voltage regulator provides 5V for the microcontroller. Each tile (slave) communicates with a master module (Arduino Uno) over an I2C-bus. All 21 tiles are connected to the same bus. The master module communicates with a PC over a USB cable. Figure 1 shows a high level scheme of the system architecture.

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*Insert Figure 1*

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*The Software*

Conceptually the system is divided into three parts: the tiles, a communication bridge and an end-user program.

The first part are the tiles. They use FSR's to measure weight and provide feedback using RGB LEDs. The software running on each tile is responsible to send out the current weight, determined by the four FSR's on the tile and activate the LEDs. The data and requests are sent over an I$^2$C bus. To limit the amount of data on the bus only the maximum weight of each tile is sent.

The communication bridge is the second part, it orchestrates the communication between the tiles and software running on a computer. Physically this runs on an Arduino Uno. It gathers data from all the tiles (via I$^2$C) and passes it through to a computer via Serial over USB. It also receives commands to set the color of LEDs of the tiles. It receives the commands over the serial bus and translates these to I$^2$C commands addressing the requested tile.

The end-user program is the third part, as is shown in figure 2.

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Insert Figure 2

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The software running on the tiles and on the communication bridge microcontroller is intentionally kept as simple as possible. It keeps many options open for the AMPEL end-user control software which has more responsibilities.

- It keeps a log with the raw values of the weights on each tile for each timestamp.
- It determines a threshold for each tile which determines if it is ON or OFF. This threshold is different for each tile due to slight mechanical differences and small discrepancies of material properties of the velostat. Environmental conditions such as temperature might affect the threshold as well, therefore, the thresholds are determined automatically before every session.
- The software also helps with creating sequences. The sequences are defined in text files which define the order of tiles and the feedback. When performing the sequence the software provides the commands to enable the feedback in each situation. Figure 3 illustrates the reference and performed sequence order.

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*Insert Figure 3*

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- The feedback type is defined in a set of plug-ins since it depends on the intended use. There is a plug-in that provides feedback via sounds using a sample bank, a sound file for correct and incorrect. Feedback via coloured light using the RGB LED's in the tile is also possible. The most simple plugin is the 'no feedback' plugin which does not provide feedback in any circumstance.  There is also a melody plug-in which provides MIDI capabilities to the system. Each tile can then drive a midi note synthesized by a configured MIDI synthesizer.
- During the performance of a sequence a log file is kept with which tiles were enabled and whether they were correct in the sequence or not and which feedback was given to the user.

## PART 2. Technical Reliability

*Participants*

This reliability study is a part of a larger pilot case control study, which was approved by the Medical Ethical Committees of universities Hasselt and Ghent (Belgium). Study flyers were used to recruit participants. Reliability data were collected from the first cycle of testing on ten healthy participants. Participants were excluded if they were pregnant, colour blind or had any neurological conditions.

*Experimental Design*

Participants underwent two testing sessions, a few days apart. During both sessions, participants were asked to walk to four experimental conditions: straight and diagonal lined paths, starting with the left and once with the right foot per condition. These paths were constructed to ensure that all tiles were stepped on per participant, as shown in Appendix 1. Additionally, during session one, general demographic information on age, height and weight were collected.

*Outcome Measures*

The inter-step-interval and total onset time per tile were derived from the log files. Per condition, an average of inter-step-interval and total-onset-time were calculated from the total number of active tiles.

## Statistical analysis

To determine technical reliability for the outcomes inter-step-interval and total-onset-time, Pearson's and Spearman's correlation co-efficient were calculated for parametric and non-parametric data respectively for the four experimental conditions. The following classification was used to categorise the correlation(26): .00-.30 'negligible correlation', .30-.50 'low correlation', .50-.70 'moderate correlation', .70-.90 'high correlation', .90-.100 'very high correlation'. A mixed model analysis of variance was applied on the outcome measures inter-step-interval and total-onset-time with sessions (one vs two) and condition (straight left and right; diagonal left and right paths) as within-subject factors. A multiple comparisons Tukey's test with Benforroni's correction was further performed as a post-hoc test when significant main effects were present. All analyses were performed using SAS JMP Pro 13.2.0 (copyright SAS Institute Inc., USA). The *significance* level was set at $p<0.05$.

**Results**

**PART 1. AMPEL**

The different elements of AMPEL was successfully combined, Figure 4 illustrates the current configuration and set-up of AMPEL.

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*Insert Figure 4*

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**PART 2. Technical Reliability**

Ten participants with mean age of 41.8 ± 18.5 , and BMI 24.8 ± 6.1 participated in the study. Table 1 provides the mean, standard deviation, upper and lower 95% mean values and between-session correlation co-efficient of the inter-step-intervals and the total-onset-time per experimental condition. As seen in table 1, high correlations were found between sessions for all conditions, indicating a good technical reliability in healthy controls.

Inter-step-intervals. A significant main interaction was found between conditions ($F(2,72)=5.0$, $p=.0095$) and sessions ($F(1,72)=18.0$, $p<.0001$). The post-hoc tests after Bonferroni correction revealed a statistical lower inter-step-intervals when performing the right straight compared to the right diagonal conditions ($t=2.98$, $p=.0108$) and during session two compared to session one ($t=4.25$, $p<.0001$).

Total-onset-time. A significant main interaction was found between session ($F(1,72)=14.7$, $p=.0003$). The post-hoc interaction revealed that the total onset time of the second session was significantly lower than the first ($t=3.85$, $p=.0003$).

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*Insert Table 1*

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**Discussion**

In this paper, we described the development of AMPEL, and provided evidence of technical reliability of inter-step-intervals and total-onset-time in healthy participants, when different routes of stepping were conducted. These outcome measures are comparable to outcomes such as reaction time, in motor learning studies which use tapping as the motor task (27). These outcomes are promising for the development of future studies investigating motor learning during dynamic balance and gait. A learning effect was also seen between the sessions, where participants walked faster in the second session compared to the first. These results can be explained given the fact that participants were not familiarised with AMPEL. In order to control for learning effects during experimental trials, the inclusion of sufficient familiarisation trials of movements on AMPEL is highly advised.

AMPEL was designed and developed with flexibility and adaptability of the system in mind. For example, the tiles can be used within different spatial configurations. The plug-in system also accommodates the investigation of novel embodied learning theories or concepts using different forms of sonification and feedback, biomarkers, or technologies such as virtual reality. Additional possibilities include investigation of interactions between multiple AMPEL users. In summary, novel study designs can be applied on the system to investigate embodied sensori-motor learning strategies in healthy, as well as in neurological populations.

Apart from using AMPEL for the purpose of understanding embodied learning or other forms of learning, the device can be used to investigate neurological interventions. For example, music supported therapy, a technique developed for upper extremity rehabilitation in stroke patients, have shown an improvement of motor functions(28). Therefore, AMPEL provides opportunities to perform music-supported therapy for lower extremity rehabilitation, for example for dynamic balance and gait. One could argue that commercially available piano pads on the floor (Monster Piano(29)) could be an alternative solution. Although this commercially available product is valuable by itself, the movements trained on these floor pianos are confounded to side-steps only, while on AMPEL, different steps (e.g. tandem steps, front steps, back steps, side-steps, etc.), or turns can be trained. Another added value for a clinical use is the access to objective data as well, to mark progress of end-users.

Moreover, given the manually adjusted plug-ins, endless possibilities of creating different mappings are possible, both in the auditory or visual conditions. The use of the device in a clinical setting therefore gives the therapist creative opportunities, as well as the possibility to change the sequences across time to either introduce progression, as well as avoid repetition and boredom. These make up essential factors in terms of (sensori)-motor learning.

## Conclusion

AMPEL was developed to accommodate different plug-ins, with the main aim to be used to investigate novel embodied learning frameworks for motor and/or cognitive neurological rehabilitation. The inter-step-interval and total-onset-time outcome measures derived from AMPEL were technically reliable in healthy participants.

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