# Perceptual studies in the use of human-computer interfaces: Sensory substitution in a sensoriomotor task

Héctor Gómez Escobar, Guillermo Ulises Ortiz Garin , Adriana López Hernández and Tom Froese | Instituto de Investigaciones en Matemáticas Aplicadas y en Sistemas (IIMAS), Universidad Nacional Autónoma de México (UNAM)

## Abstract

The sensoriomotor approach of perception emphasizes the role of a loop between motor activity and the subsequent sensations an agent produces by engaging with the world. Along this line and following philosopher Martin Heidegger, enactivist theory proposes that tool use becomes a part of the cognitive system as a coupling rule through which it engages with its environment (transparency), rather than being just a way by which the agent uses part of the environment to gather information (opacity). Following these assertions, experimental studies have shown a series of cognitive modifications modulated by tool use, such as neural, perceptual, behavioral and experiential changes. Using dynamical systems methods, body image perception tests and qualitative methodology, we asses different ways in which a human-computer interface can become a tool when used by an active agent. For that purpose, we have participants go through a navigation task using a couple of "Enactive Torches", a custom-built human-computer interface that allows for the recollection of sensorimotor data in real time. Before and after this task, we replicate the body image perception task by Cardinalli et al. (2009) to study fluctuations in the perception of the arm's length following tool use. Also, we applied questionnaires to gather subjective experiential data. Finally, trough time series information flows, we study the emergence of perception as complex sensorimotor phenomenom.

## Perception and tool use in enactivist theory: The dynamics of body-environment systems

The enactivist approach is based on mutually dependent concepts: autonomy, sense making, emergence, embodiment, and the subjective experience of a cognitive agent (Varela, Thompson, Rosch, 1997). It considers sensory output as part of the sense making cycle, so no mental representations are needed. This way, enactivism and it's view on the psychology of tool use is fully compatible with the perspective of an extended and embodied mind (Proulx, 2004, Clark, 2008). Moreover, it's consistency with artificial life results in brain-body-environment systems (Beer, 2009) makes it prone to be studied trough a dynamics systems theory lens (Schöner, 2008; Kelso 1997).

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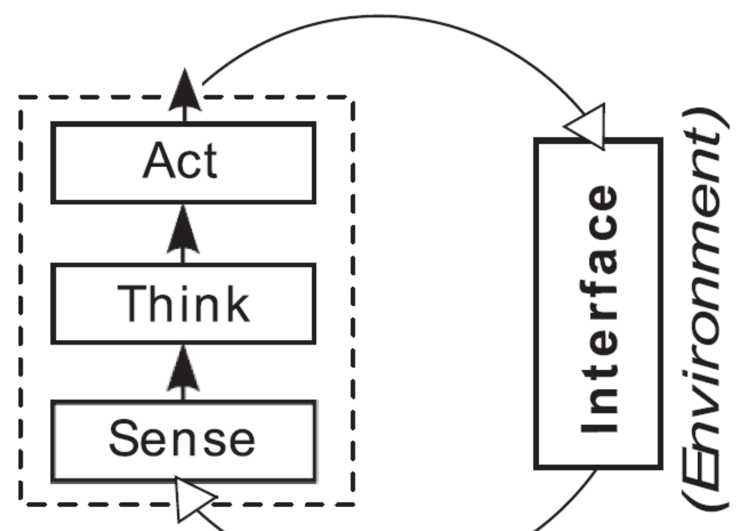
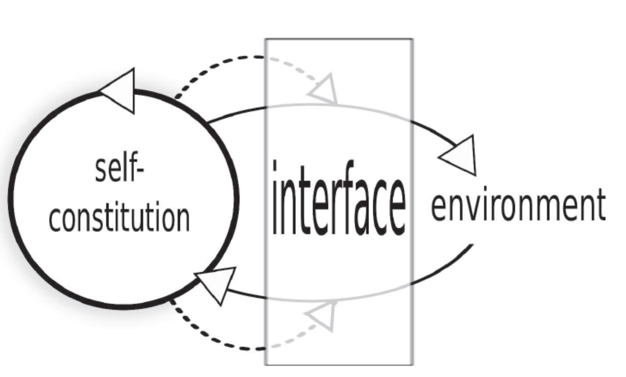
Tool use has shown to have an impact on neural activity, the body schema perception, and the user experience. Evidence of this comes not only from sensory substitution tools, but sensory enhancement tools have shown it as well; from the enactivist perspective, it is said they increase sense making within the user (Froese & Spears, 2007). Hence, an enactive interface is a tool that allows new possibilities of action through a new coupling with the world.

A) Traditional cognitive model of tool use.




B) Enactive model of tool use.

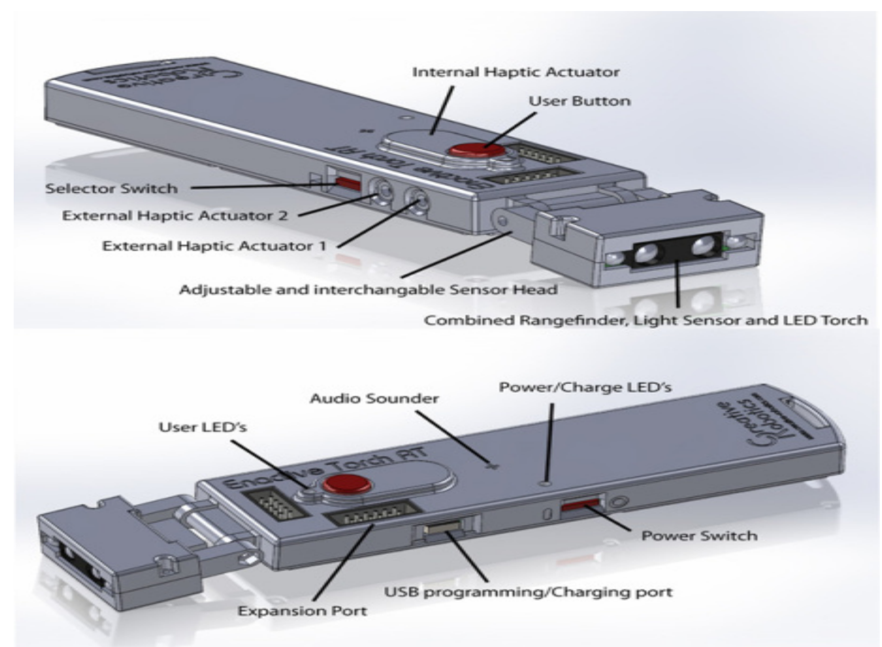



The Enactive Torch is a minimal device that transforms input from nearby objects (obtained through an infrared) into a motor vibration output. This tool is secured to the wrist of a subject, so that haptic input is received as if it were visual information. (Froese et al., 2012)

## Tool description: Enactive Torch

- 2 Accelerometers that give information about the movement of the device.
- 2 Infrared sensors that provide information about the distance of objects that reflect light.
- 2 Haptic actuators, through which a vibratory output is given.
- 1 Arduino chip that allows to program modifications in these parameters.
- 1 Bluetooth device that allows the recording of these values in real time.

Given these characteristics, time series analysis becomes possible in multiple scales, feature that lacks in most (if not every) sensory substitution device. Below, the new model of the ET used in the maze tasks of the present study.




## Objetive

Identify immersion measurements in the use of human-computer interfaces (interaction dependent dynamics of an extended system), through time series analysis, proprioceptive tasks, and qualitative analysis.

## Propioception task and questionnaire

The experiment carried out by Cardinalli et al. (2009) is replicated as a proprioception task. Each participant is given light touches in different parts of the arm (fingers, forearm and elbow) in a random order; this is done before and after a motor task. The participant is kept blindfolded and is asked to indicate where they felt the touches. In our case, variability in these results will be evaluated in a pre-test / post-test mode, with a navigation task that might have potential effects.

It is important to understand the meaning of people's actions at the time that the behavior of interest is carried out. In order to acquire validity, one should use varied data gathering techniques that might allow the emergence of new information and patterns of behavior otherwise unnoticed (McAuliffe & McGann, 2016). Therefore, for this experiment participants are asked to answer a questionnaire regarding their subjective experience of the procedure. They have to rate how much they agree or disagree with a series of statements that describe potential experiences they might encounter. These statements inquire about the participant's focus of attention while solving the task (eg. in the tool's vibrations), about the senses they think they are using or they feel are guiding them, and about how comfortable they find the tool to be. Also, participants need to answer a few open questions related to the thoughts and feelings they experienced during the navigation task. In this section, they talk freely about their experience and about the meaning they give to the Enactive Torch use per se.

## Experiment

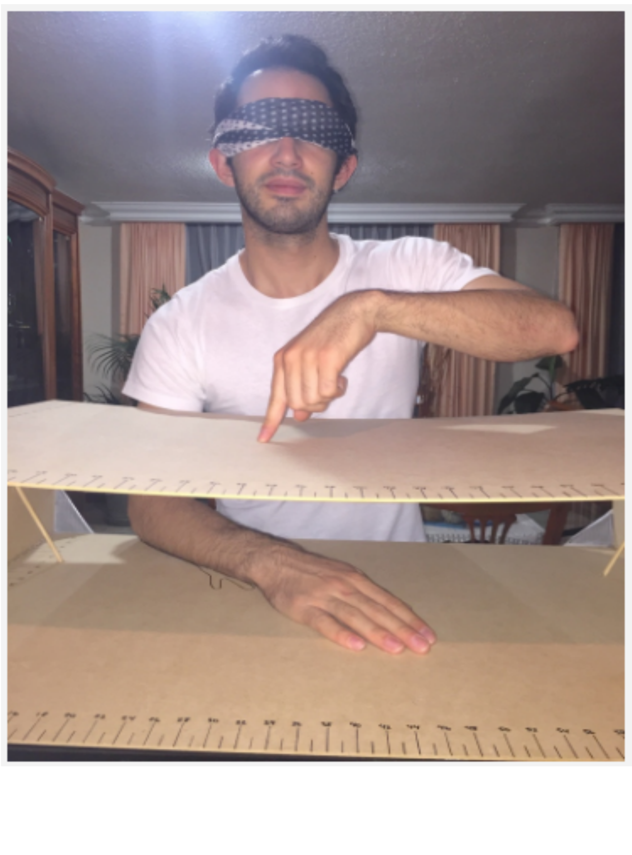
The experiment consists of two parts: the navigation task and the measurements of the body schema. Participants are blindfolded during the whole experiment. The perception of the participant's body schema (specifically, the perception of the arm's length) is measured twice: the first time is done before the navigation task, and the second time after it.

The navigation task lasts 50 minutes. Participants have to walk through an arrangement of three aisles (that eventually leads to the same place), guided by auditory stimuli under the control of the researchers (delivered via Bluetooth speakers). In the instructions participants are told to follow a pitch that may come from different places; whenever they reach the speaker that is currently generating the sound, a transition is made and another speaker takes its place. Each corridor has three obstacles that force a sensorimotor decision, for which the wrong guess leads to a "dead end" and makes it necessary for the participant to trace back his own steps. In the instructions, participants are warned about having to avoid twelve obstacles, and about having to go through four sources of sound without stopping. This allows for continuous time series in which the learning of the navigation action trough explorative motor behavior with the human-computer interface has become the only way to successfully finish the task.

Finally, the second arm measurement is performed at the end of the navigation experiment. Furthermore, questionnaires are given to the participants at the end of the experiment in order to make a qualitative analysis.

Left: A photograph of one of the subjects during the pilots of the ET's navigation task

Right: A pilot subject performing the arm touch experiment.



## Analysis

The data collected from the time series that give information about location and manual movement in the Enactive Torch (accelerometers and speedometer) and sensory coupling (infrared sensors) will help study the transfer of information associated with success in the task. Specifically, in data analysis it will depend on the structure of the time series collected, with an emphasis on studying the transfer entropy and sensoriomotor complexity as an effect of the tool use.

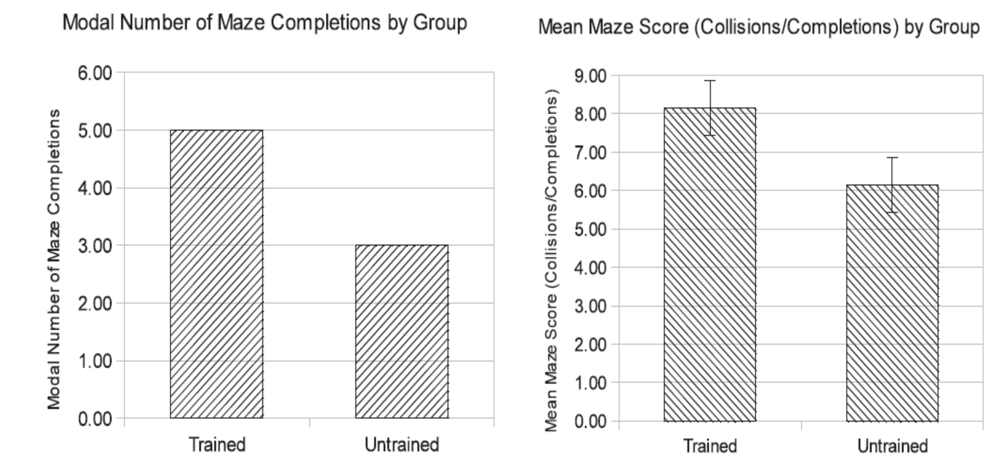
The transfer entropy will be calculated for each accelerometer-sensor-motor triad, so that once the task is completed it can be studied whether there is a correlation over time with incremental levels of information flow.

On the other hand, measures that do not imply informational analysis are seeked, so that it is possible to identify the presence of 1/f noise in the time series of the accelerometers. This is done following the results of Dotov et al. (2010), in which the use of fractal analysis demonstrates interaction-dependent dynamics in the human-tool system, and Dotov et al. (2017), in which multi-fractals are used to demonstrate the inclusion of the tool in the cognitive system.

## Results

Previous findings (Froese et al., 2012) show negative results in the distortions of the corporal image of the arm.

Similarly, although there was a relative success rate in the task, there was no way to analyze the time series. Pilot studies suggest that participants endure navigation times of approximately 50 minutes; also, they show a fluctuation in the perceptual task when specific points of the arm are measured (eg. the wrist).




(Froese et al., 2012)

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