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SOP- habituation laboratory: An interactive tool for simulating the basic behavioral features of habituation

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Abstract

This paper presents an open-source online tool for introducing psychology students to the major theoretical and empirical facts of habituation. The tool was designed in a way that combines theory and data through simulated experiments. The simulations exemplify how the priming theory of Allan R. Wagner accounts for the set of behavioral characteristics of habituation proposed by Richard F. Thompson and W. Alden Spencer in 1966. Through this interactive platform, the user can learn the basics of the theory and examine how it accounts for the empirical facts with different parameters. Instructions and commands are provided in three languages: English, Spanish, and Portuguese.

Keywords Habituation · SOP · Priming · Open-source · Online educational tool · Teaching experimental Psychology

Habituation is defined as a decrease in responding to a repeated stimulus that is not due to sensory adaptation or effector fatigue (Harris, 1943; Rankin et al., 2009). This very basic form of learning has been investigated in the laboratory for more than eight decades (Harris, 1943; Humphrey, 1933; Prosser & Hunter, 1936) and is one of the first topics being taught in most introductory courses in animal learning. Due to the apparent simplicity of this phenomenon, its theoretical approaches and empirical facts can be used simultaneously to create learning experiences. One way of doing this, which has gained progressive acceptance among science educators, is through computer simulations (Develaki, 2019; Rutten, Joolingen, & Veen, 2012; Smetana & Bell, 2012). Thus, the goal of this paper is to provide students with a user-friendly tool to simulate the major empirical facts of habituation and to examine some of the theoretical mechanisms that have been proposed to explain these observations.

In this first version of the tool, we have chosen to focus on the set of ten behavioral characteristics of habituation listed by Rankin et al. (2009) which is an upgrade of the original characteristics proposed by Thompson and Spencer (1966). This list contains a description of several empirical observations whose reality has remained relatively unquestionable over the years, so it provides an ideal point of departure for students being introduced to the topic.

In attempts to explain these facts, scientists have formulated several theories of habituation (for critical reviews, see Hall, 1991; Mackintosh, 1987; Siddle, 1991; Thompson, 2009). This laboratory focuses on the priming theory of Allan Wagner (1976, 1978) and specifically in its quantitative rendition, known as the sometimes-opponent processes model (SOP model; Wagner, 1981; Mazur & Wagner, 1982; Whitlow & Wagner, 1984). Based on this theory, we built a simulator that makes specific predictions as some parameters, such as stimulus intensity, number of trials, or inter stimulus interval, are varied. The students will be able, thus, to run simulated experiments examining the conditions under which a specific phenomenon is to be observed according to the theory and to assess when the theory succeeds and fails.

It has been shown that SOP embraces reasonably well the ten features of habituation and makes interesting predictions about further phenomena whose empirical status is still controversial (Uribe-Bahamonde et al., 2019; Whitlow & Wagner, 1984; Wagner & Vogel, 2010). Hence, users might learn also about some ongoing issues in the field.

Differing from other virtual tools like Sniffy Pro (Graham, Alloway, & Krames, 1994), the laboratory that we present in this paper does not emulate the behavior of a specific animal in a specific experimental setting, but instead simulates the predictions of the SOP model for a series of conceptual experiments that have been or could be done with a range of species and procedures. We believe that by working simultaneously

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on data and theory, introductory students could get a good sense of how research is conducted in the field.

In the next sections, we provide guidelines on the use of the SOP-habituation laboratory. First, we present the basic operating instructions and then, by means of examples, we illustrate how the tool introduces students to the experimental analysis of habituation and to the SOP model. Finally, we display an example on how to conduct simulated experiments.

Operating instructions

A simulator for the SOP model was programmed using Stella Architect software v1.5.1 (isee systems, 2017). With this simulator, we created an open access interface called "SOP-habituation laboratory", which can be accessed at the URL http://vogelab.com/habituationlab.

By clicking on the link, users can run the tool on any device with a web browser. Once the SOP-habituation laboratory has been launched, the user will see a window displaying a menu with three options: a) An overview of the experimental analysis of habituation, b) an overview of the priming theory of habituation, and c) simulating the ten features of habituation.

An overview of the experimental analysis of habituation

In order to get the students acquainted with the subject matter and to provide them with an idea of the phylogenetic range across which habituation is studied, this section presents audiovisual material on two animal models: The escape response of the crab to the movement of an overhead form (e.g., Brunner & Maldonado, 1988) and the startle response of humans to auditory or tactile cues (e.g., Landis & Hunt, 1939).

This section of the platform begins with a screen providing a basic definition of habituation followed by short videos of a crab and a human responding to simulation in their relatively natural habitats. Next, the user is directed to a screen depicting a schematic drawing of the apparatus and procedures used for the experimental study of habituation of these species, which is followed by plots summarizing the results of actual experiments on short- and long-term habituation. The last part simply contains an introduction to the ten characteristics of habituation. Fig. 1 displays screenshots of these elements.

An overview of the priming theory of habituation

Since the SOP-habituation laboratory is an educational tool for introductory courses, a simplified version of the SOP model is presented in this section. For a more detailed exposition of the theory, the reader may consult Mazur and Wagner (1982), Whitlow and Wagner (1984) Vogel, Ponce, and Wagner (2019), Vogel, Ponce, and Brandon (2020) and Wagner (1981). The theoretical and practical assumptions of the simulations of this article are described in the supplemental material.

After a few introductory slides, the exposition begins with a couple of animated cartoons and a graphical sketch illustrating the representational dynamics of the model. The goal of this sequence is to introduce students to the idea that the representation of any stimulus involves a large set of elements that can be in one of three states of activity: Inactive (I), primary activity (A1), and refractory (A2). The three states might be viewed as containers connected by pipes through which the elements flow. Before stimulation, all elements are in the inactive state, so this box is full and the other two are empty. If the stimulus is turned on, a proportion, of elements, p1, flow to the A1 box and produce a response of certain amplitude. Once in the A1state, the elements flow, first to the A2-state with probability pd1, and then back to inactivity with probability pd2, where they remain unless a new presentation of the stimulus occurs (see Fig. 2a and b).

Once the fundamentals of stimulus representation in the theory have been established, students are moved towards SOP's account of short-term habituation. Here, users watch a pair of animated cartoons in which a person receives two presentations of the stimulus (Fig. 2c). The first video presents a case in which the stimuli are sufficiently separated in time, so that the person responds equally to both stimuli. In the second video, the interval between the two stimuli is considerably shorter and no response is observed to the second stimulus. This is so because when the second stimulus occurred, all elements were still in the refractory state due to prior stimulation. This feature of SOP is the core assumption of priming theory which states that "when an event is pre-represented ("primed") in short-term memory (STM) further corresponding stimulation is rendered less effective than it otherwise would be" (Pfautz & Wagner, 1976, p.107). Since this sort of priming is occasioned by prior presentation of the same stimulus, Wagner (1976) referred to it as "self-generated priming".

The cartoons explaining self-generated priming represented an all-or- none situation with respect to the response. Nonetheless, SOP regards the response as a quantitative variable whose magnitude depends on the proportion of elements in the primary state of activity (A1). The instantiation of this property is presented in the next slide, which depicts the distribution of elements in the A1 and A2 states over time for a simulation in which two presentations of the stimulus were separated by a few time steps or simulated moments. Figure 2d presents an example of one possible outcome of this type of simulation. The results are displayed dynamically by plotting the proportion of elements in the A1 and A2 states

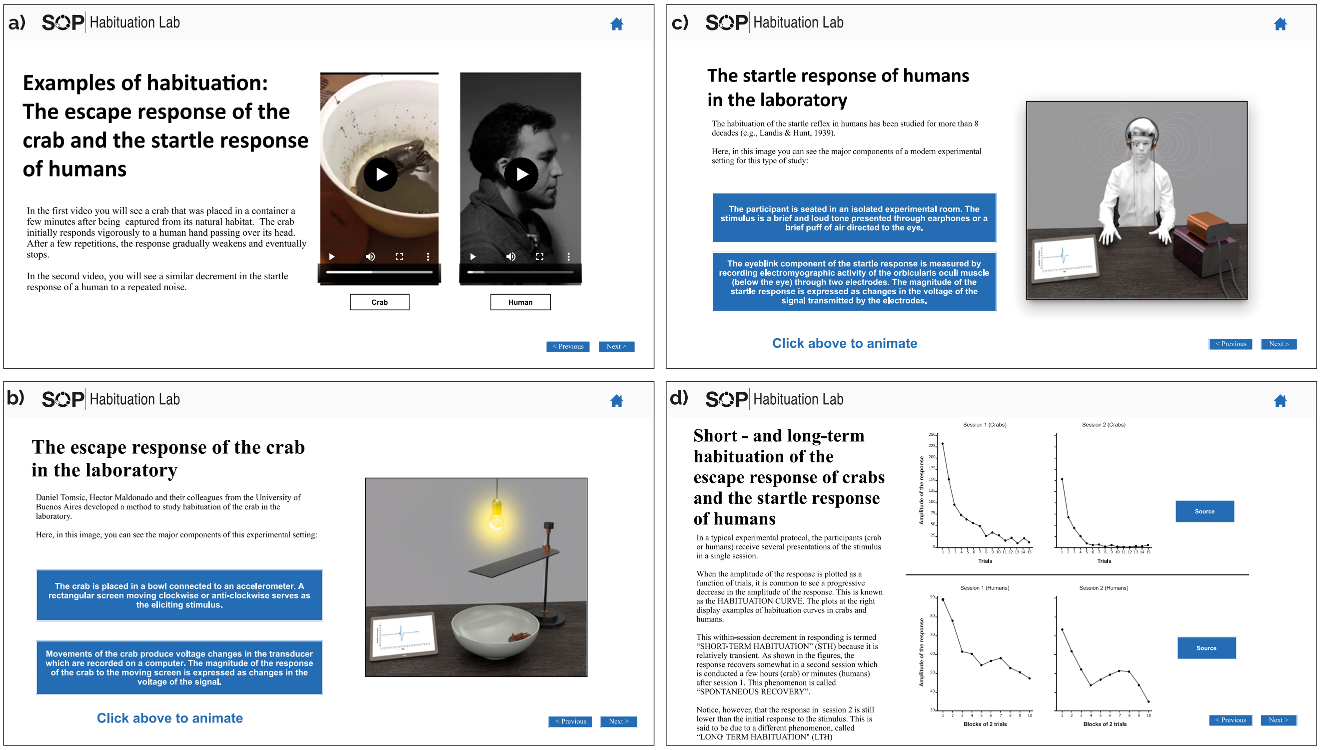

Fig. 1 Screenshots of the sequence of windows that appear in the section "An overview of the empirical facts of habituation"

over time. The simulation shows that the presentation of a brief stimulus produces a rapid and transitory increase in the proportion of the elements in the A1-state, followed by an increase in the proportion of elements in the A2-state and by a very delayed return of elements to inactivity. The figure makes evident that after the first presentation of the stimulus

Fig. 2 Screenshots of the first sequence of windows that appear in the section "An overview of the priming theory of habituation". This sequence presents the basics of SOP and shows how it accounts for short-term habituation

there is a long period of time in which a substantial proportion of elements are in the A2-state, which means that they are not eligible for reactivation if the stimulus was presented again during this period. The consequence of this is apparent in the fact that the second presentation of the stimulus is less effective in provoking A1 activity, and hence it is less effective in provoking the response. Users are prompted to verify that the effect disappears with a much longer interval between the stimuli.

The laboratory proceeds with a description of SOP´s account of dishabituation. This is done, again, through an animated cartoon, a graphical sketch and a simple demonstration (Fig. 3a, b, and c). The students are first told that dishabituation refers to a recovery in responding to a habituated stimulus when a novel stimulus or distractor is interpolated between two presentations of the stimulus. SOP explains this phenomenon by assuming that the distractor has the power of speeding up the return of elements to inactivity. Specifically, the presence of the distractor influences the processing of the target stimulus by increasing its decay probabilities, pd1 and pd2, as a function of its own A1 and A2 activity. Thus, in the presence of the distractor, the elements of the target stimulus will be available for activation sooner than otherwise. In the final slide of this series, the students watch a very simple demonstration of dishabituation according to SOP.

The goal of the first part of this section was to show that self-generated priming is a potential mechanism to account for short-term habituation and dishabituation. Of course, these are transient effects that disappear when sufficient time has elapsed from the last presentation of the stimulus, for instance, from one session to another. At this point, it should be clear to

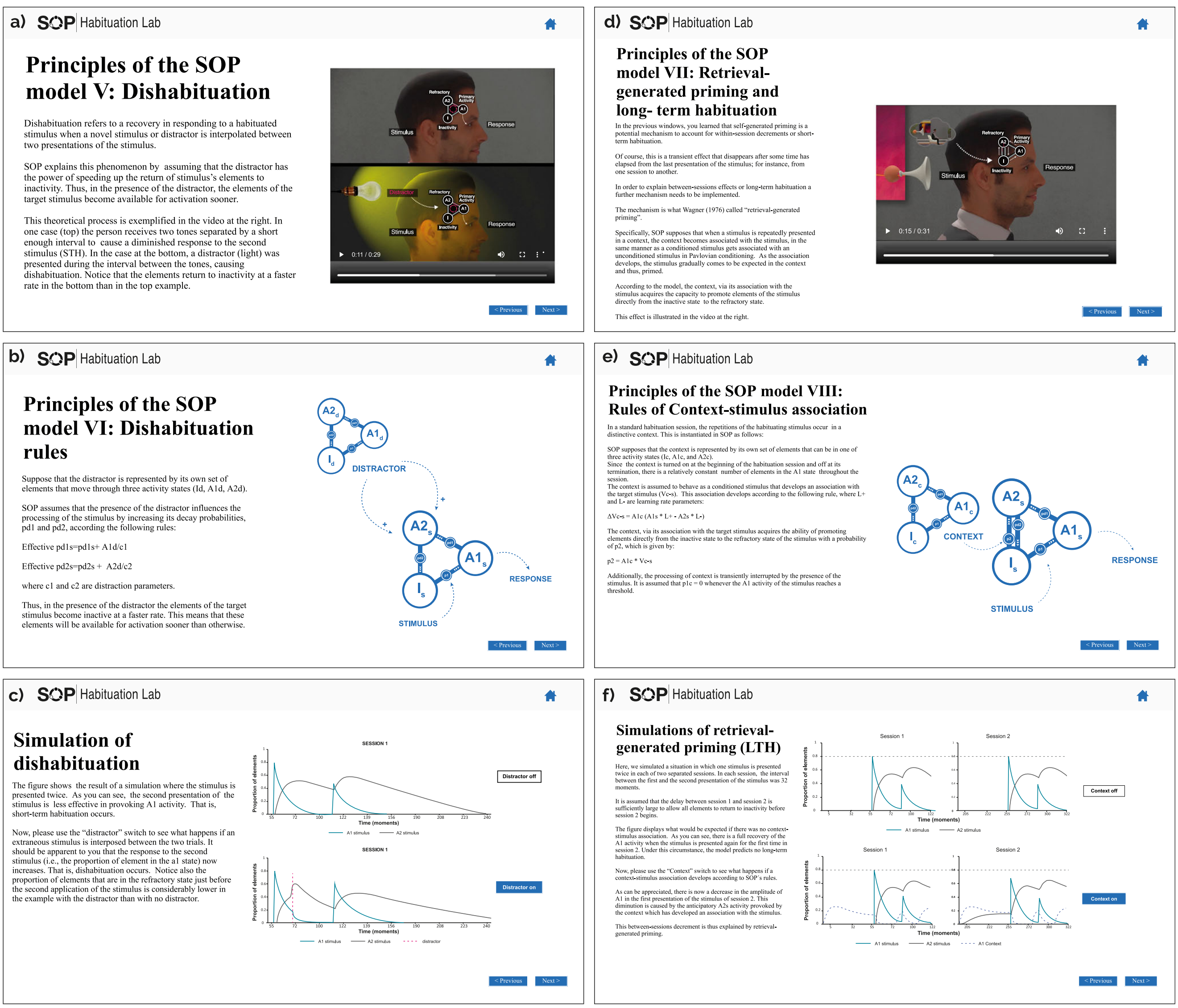

Fig. 3 Screenshots of the second and third sequence of windows that appear in the section "An overview of priming theory of habituation". Panels a, b, and c, depict windows involving dishabituation and panels d, e, and f depict windows involving long-term habituation

the students that to account for between-session effects or long-term habituation a further mechanism needs to be implemented. The mechanism is what Wagner (1976) called "retrieval-generated priming", which is explained in the last part of this section. Here, the students first watch an animated cartoon showing that after repeated exposure, the habituating stimulus comes to be expected in the context (Fig. 3d). This expectation means that the context, via its associative link with the stimulus, acquires the capacity to promote elements of the stimulus directly from the inactive to the refractory state of activity. The rules of context-stimulus interaction are briefly outlined in the next window (Fig. 3e). In the final window, the user would be able to examine the quantitative consequence of the association between the context and the stimulus (Fig. 3f).

Simulating the ten features of habituation

At this point of the laboratory, students should have learned a few critical aspects of the experimental analysis of habituation and the essentials of one of the most important theories that have been proposed to explain this phenomenon: the SOP model. Next, they will be asked to integrate this knowledge by conducting simulations of the predictions of SOP for each of the ten features of habituation.

For the sake of simplicity, the simulations assume that the strength of the response to the habituating stimulus is equivalent to the proportion of elements of the habituating stimulus that are in its A1 state of activity. Consequently, the dependent variable in all simulations is called "response strength (A1)". The results of the simulations are presented in graphs displaying the maximal strength of the response (*y*-axis) as a function of trials (*x*-axis).

In the simulations, the user will be free to choose the value of some parameters but not all. Those parameters that we deemed less critical for a given feature of habituation have fixed values. Specifically, in all simulations the duration of the habituating stimulus was 1 moment and its pd1 and pd2 values were set at 0.1 and 0.02, respectively. The learning rate parameters, L+ and L-, were set at 0.1 and 0.01, respectively. To simulate the transition from one session to another, all activity was set to zero at the end of the session. The only value that was carried over from one session to the next was the strength of the context-stimulus association.

Figure 4 presents the general structure of the simulation windows. On the left-hand side of the screen the user can read a summarized description of the target characteristic of habituation copied from Rankin et al. (2009) along with an explanation of the structure of the simulation. At the right-hand side of the screen, there is a chart displaying the predicted peak response as a function of trials. A set of controls for changing some parameters of the simulation and a run button are displayed at the right and below the chart, respectively. The tabs in the left hand-bottom side of the screen allow navigation to the simulations of other characteristics in any order.

Advanced students and researchers wishing to examine the theory with a broader range of phenomena and parameters, can use a more flexible and comprehensive simulator, which is described in the supplemental material.

Concluding comments

In this paper, we presented an online educational resource, the SOP-habituation laboratory, which provides an introduction to both, theoretical and experimental analyses of habituation. The resource is free access, runs in any platform and does not require installation of software. Our tool can be regarded as complementary to other in vivo (e.g., Nolan, 2004) or virtual (e.g., Graham et al., 1994) laboratories and to introductory textbooks of learning.

In the current version of the tool, we focused on a few empirical facts and in just one theory. Of course, the SOP-habituation lab does not even nearly exhaust the rich empirical and theoretical work done in this area. The SOP model, for instance, is just one among several theories of habituation. The best-known and perhaps most accepted approach is the dual-process theory of Groves and Thompson (1970), who proposed that the behavioral consequence of stimulus repetition depends on the interaction of a decremental process or habituation and an incremental processes or sensitization. The existence of these two opposing processes is suggested by the common finding that responding during habituation procedures exhibit an initial increment followed by a decrement relative to control conditions (e.g., Borszcz, Cranney, & Leaton, 1989; Davis, 1974; Groves & Thompson, 1970; Meincke, Light, Geyer, Braff, & Gouzoulis-Mayfrank, 2004).

We have chosen not to use the dual-process theory here because it has not been formulated in a quantitative fashion and because its principles can be studied in virtually any textbook of learning. It should be said, however, that this prompted us to leave untreated the phenomenon of sensitization in our tool, which is very easily explained by the dual-process theory but not so by SOP. Wagner and Vogel (2010) showed that SOP can account for this phenomenon by assuming that the repetition of a significant stimulus in a given context, apart from provoking the expectation of the stimulus in the context, can also result in the development of conditioned emotional responses triggered by the context that enhances the response to the habituating stimulus itself. They suggested that emotive sensitization competes with habituation, such that habituation might be obscured by sensitization. In contrast to dual-process theory, SOP assumes that sensitization is controlled by the same context that controls habituation and as such, it would not be necessarily a transient effect.

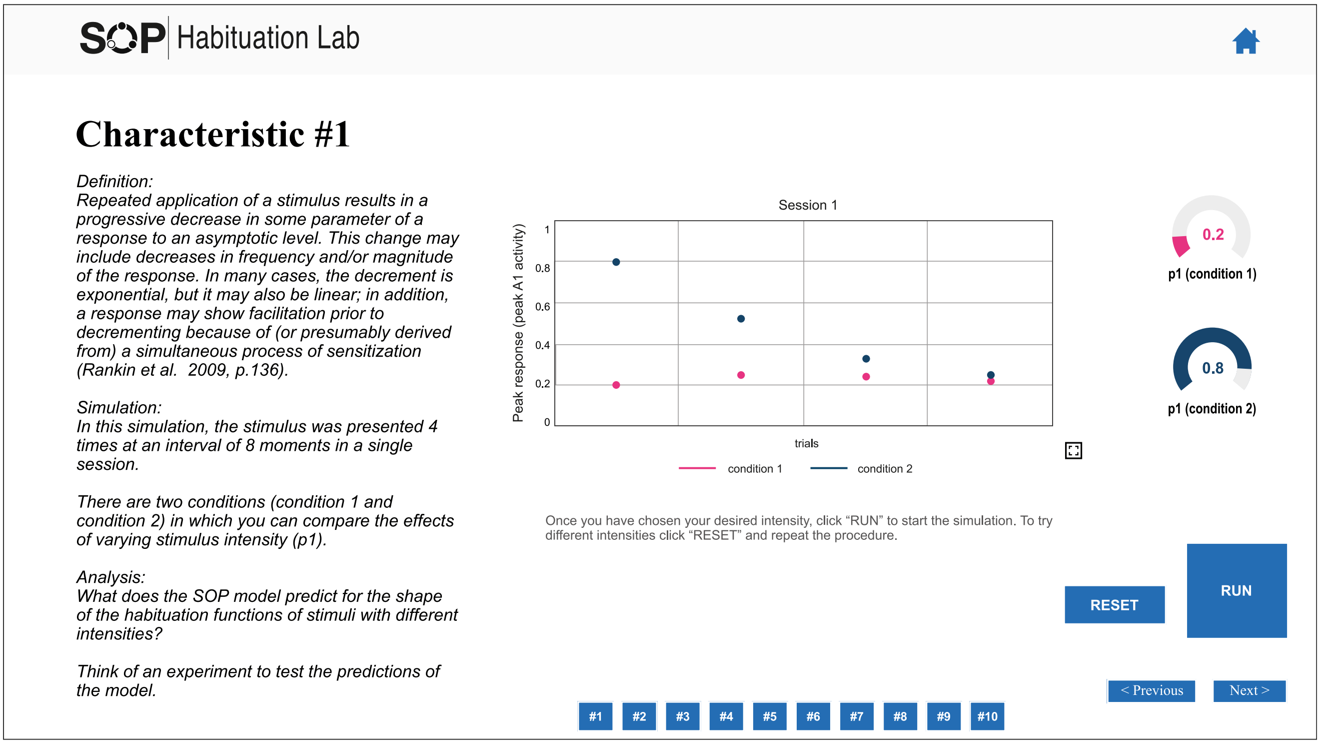

Fig. 4 An example of the general structure of the windows for simulating the ten characteristics of habituation

The strong prediction of SOP on the contextual control of habituation and sensitization is still a debatable issue, with some positive (Jordan, Strasser, & McHale, 2000; Pinto, Becerra, Ponce, & Vogel, 2014; Reyes-Jimenez, Iglesias-Parro, & Paredes-Olay, 2020; Tomsic, Pedreira, Romano, Hermitte, & Maldonado, 1998) as well as negative results (e.g., Marlin and Miller, 1981; Jordan et al., 2000). We left these complex issues to motivate further study in the last window of the tool.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.3758/s13428-021-01548-y.

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