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An extension of the Rescorla and Wagner Simulator for context conditioning

Esther Mondragón (corresponding author)

Centre for Computational and Animal Learning Research

St Albans AL1 1RQ, UK

e.mondragon@cal-r.org

Eduardo Alonso (corresponding author)

Department of Computer Science, City University London

London EC1V 0HB, UK

E.Alonso@city.ac.uk

Alberto Fernández

Escuela Técnica Superior de Ingeniería Informática, Universidad Rey Juan Carlos

Madrid 28933, Spain

Jonathan Gray

Department of Computer Science, City University London

London EC1V 0HB, UK

Abstract

This paper introduces R&W Simulator version 4, which extends previous work by incorporating context simulation within standard Pavlovian designs. This addition allows the assessment of: 1) context-stimulus competition, by treating contextual cues as ordinary background stimuli present throughout the whole experimental session; 2) summation, by computing compound stimuli with contextual cues as an integrating feature, with and without the addition of specific configural cues; and 3) contingency effects in causal learning. These new functionalities broaden the range of experimental designs that the simulator is able to replicate, such as some recovery from extinction phenomena (e.g., renewal effects). In addition, the new version permits specifying probe trials among standard trials and extracting their values.

Keywords: Rescorla and Wagner model; error prediction learning; context conditioning; compound stimuli; configural cues; open-source simulator.

1. Introduction

In [1] we introduced a simulator of the Rescorla and Wagner model [2] that incorporated algorithms to work with stimulus compounds and configural cues [3]. A new version of the R&W Simulator, version 4, has been released, which includes an additional functionality to simulate contexts.

The study of context effects has become one of the major research topics in learning. Theoretically, the role of the context [4][5][6][7] and its neurological correlate [8][9][10][11] are still subject to debate. In practice, contextual cues have proved to be critical in the treatment of several clinical conditions, such as drug and alcohol addiction [12], and anticipatory nausea following chemotherapy in cancer patients [13], to name just a few.

Rescorla and Wagner's predictions and well-known limitations [14], are critical when assessing associative principles and are commonly used as test-beds for associative properties. Thus, an accurate, user friendly and wide-ranging simulator of the model, able to represent as realistically as possible experimental conditions, including discrete stimuli as well as contexts, will provide a valuable tool to the community.

R&W Simulator 4 runs in any platform, does not require installation and can be downloaded free from http://www.cal-r.org/index.php?id=R-Wsim.

2. The R&W Simulator and contexts

The Rescorla and Wagner model is a formalization of associative learning that describes the progressive increase in the weight of a stimulus association when the stimuli are experienced paired repeatedly. Applied to classical conditioning, the amount of increase in the associative strength (V) of a conditioned stimulus (CS) that signals the occurrence of an unconditioned stimulus (US) is proportional to the degree to which the US is unexpected at that point. With each CS-US pairing (reinforced trials) the discrepancy between the predicted and the current outcome (the predicted error, ΔV) is reduced. Thus, early pairings result in large prediction errors that decrease in size as learning progresses. As a consequence, learning, denoted as the accumulative increase in associative strength, results in a negatively accelerated curve that reach asymptotic level at the point in which the CS fully predicts the US.

Formally, the predicted error and associative strength of a stimulus X at the trial n is described as follows

$$\Delta V_X^n = \alpha\beta(\lambda - V_{\sum x_i}^{n-1}) \quad (1)$$

$$V_X^n = V_X^{n-1} + \Delta V_X^n \quad (2)$$

where α and β are constants representing the salience of the CS X and of the US respectively, λ is the maximum amount of learning that can occur for that given US, and $V_{\sum x_i}^{n-1}$ the cumulative amount of learning for all present stimuli up to trial $n-1$.

In R&W Simulator 4 the context has been implemented as an additional cue, an ordinary background stimulus, which is always present throughout the experimental session. Contextual cues, often assumed to have a low salience, acquire associative strength during reinforced trials and lose it during non-reinforced. In addition, unlike a standard stimulus, contextual cues lose associative strength during the inter-trial interval (ITI), a loss that is proportional to the interval relative length.

Figure 1 illustrates (a) the distribution of associative strength gained by a context and a CS during excitatory Pavlovian training with an ITI/CS ratio equal to 4, (b) the course of CS conditioning when no context is included in the simulation, and (c) the progress of context conditioning when the context is the only simulated cue (context conditioning). Following each conditioning trial, the associative strength of both the CS and the context increases regardless of whether they are conditioned together or independently. During the ITI, however, unlike the CS that terminates after each trial presentation, the context remains present, an experimental condition that is formally equivalent to extinction and that results in a loss of associative strength. As any other stimulus, the context competes with other cues to win associative strength, that is, the context comes to form part of the summed error term, subtracting some of the available strength that the CS could otherwise acquire; likewise, the CS also reduces some of the strength that the context could obtain.

Figure 1 about here.

Whenever a cue is tested, the associative strength gained by the context in which it appears also contributes to the behavior observed. The algorithms implemented in the simulator allow representing and computing this cumulative value by considering stimulus compounds as units composed by discrete cues and the context in which they occur. Context-stimulus compounds can be formed when there is an overlap, and their associative strength is determined by the sum of the stimulus' and the context's respective associative values. Moreover, as with standard cues, the simulator encodes the possibility of generating context and stimulus configural cues, that is, additional stimuli that represent a unique feature of their combination.

In the simulator, the user can choose to work with contexts by selecting "Context Simulation" in the "Setting" menu. Six distinct contexts are available to be assigned and their salience configured per phase, with a maximum of one context in each phase. To stipulate the context loss of associative strength during the ITI, the user must enter a "ITI/CS ratio". By default the context salience and the ITI/CS ratio are set to 0.15 and 5 respectively.

3. Test results

We have chosen two well-known phenomena in the associative learning literature to exemplify the simulator's new functionality: context blocking of a discrete cue, and renewal.

3.1. Context Blocking

When an unconditioned stimulus (US) is presented in the experimental apparatus before being used as a reinforcer in a Pavlovian CS-US training, conditioning is often weaker than when no US has been pre-exposed [15][16]. Considerable research has been conducted around this phenomenon, predominantly in fear conditioning preparations [17]. Standard associative models assume that during the US pre-exposure phase, contextual cues become associated. Thus the associative strength gained by the context will block conditioning to the CS when later introduced due to cue competition. We simulated this paradigm by giving 12 US presentations in Phase

1 before conditioning a target stimulus (X) with the same US in Group Blocking; Group Control received the same treatment but no US was programmed to occur during Phase 1. Figure 2 shows the results of this simulation. The associative strength of X during conditioning in Group Blocking is correctly predicted to be lower than in Group Control.

Figure 2 about here.

3.2. Renewal

Renewal refers to a set of conditioning results that show a recovery of the conditioned response following an extinction treatment when the CS is tested in a context other than the one in which extinction occurred [18][19]. The renewal effect is particularly noticeable when the test context and the conditioning context are the same.

The renewal paradigm has been extensively investigated in drug addiction studies, including cocaine [20], heroine [21], nicotine [22], and alcohol [23], as well as in anxiety disorders [24] and post-traumatic stress disorders [25].

We simulated a set of different renewal instances to test the Context-CS compound functionality. Four groups were considered, in all of which a target stimulus T was conditioned for 10 trials (Phase 1), then extinguished during another 10 trials (Phase 2), and, finally, tested in 3 further trials (Phase 3). The groups differed depending on the context in which each learning phase was given: Group AAA received all phases in the same context (Context Φ); in Group AAB conditioning and extinction took place in Context ψ whereas test was administered in a different context (Context Φ). Group ABA received conditioning and test trials in Context Φ but extinction was delivered in Context ψ; lastly, in Group ABC each phase was programmed to occur in a different context, Context Φ, Context ψ and Context Ω, respectively.

Figure 3 about here.

Figure 3 shows the simulated combined associative strength of the context and the cue, represented as a context-stimulus compound obtained during the test phase. An inspection of these values reveals that recovery after extinction was greater in Group ABA that received extinction in a different context from conditioning than in all other groups. Groups AAB and ABC showed and intermediate level of recovery in comparison to the levels predicted for Group AAA, in which all phases occurred in the same context. The simulator correctly reproduces the pattern of empirical results. We are aware that evidence supports that contextual associative strength is neither necessary nor sufficient for explaining renewal [26][27], and it is not our intention to claim so. Nevertheless, these are clear predictions of the Rescorla and Wagner model and as such have been incorporated as an example of the simulator capabilities.

4. Other improvements and Conclusions

The R&W Simulator 4 offers an algorithm to specify probe trials by adding a hat symbol (^) immediately after the cue (e.g., 10AB^+). The calculated associative strength of the marked stimulus during these trials will be copied to the output and to the figures as a snapshot of the chosen cue.

In summary, the simulator provides a user-friendly, fast and free tool to simulate the Rescorla and Wagner model. It allows both discrete cues and context simulation, and it computes compound stimuli formed by different stimuli and stimulus-context compounds. It also permits defining configural cues to add to the compounds. The addition of context simulation is an important extension since the role of the background in learning is theoretically controversial and of practical relevance in the treatment of several clinical conditions.

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Figures Captions

Figure 1. (a) Simulated acquisition of associative strength during Pavlovian training of a discrete CS (filled circles) and the experimental Context (open circles) in which conditioning takes place; (b) simulated CS acquisition of associative strength when no context assumed in the simulation –CS alone (filled squares); (c) and context associative strength acquisition assuming isolated context-US presentations –Context alone (open squares). Simulation parameters: $\lambda = 1$; $\beta+ = 0.5$; $\beta- = 0.45$; $\alpha(CS) = 0.3$; $\alpha(Context) = 0.25$; number of trials = 10; ITI/CS ratio = 4.

Figure 2. Screenshot of the simulation results showing acquisition of associative strength during a conditioning test phase of a target stimulus X following US pre-exposure (Group Blocking) or following non-reinforced pre-exposure to the context (Group Control). Simulation parameters: $\lambda = 1$; $\beta+ = 0.6$; $\beta- = 0.5$; $\alpha(X) = 0.4$; $\alpha(\Phi) = 0.25$; number of pre-exposure trials = 12; number of conditioning trials = 5; ITI/CS ratio = 2. Checked boxes below the figure legend indicate the selected group and corresponding cues.

Figure 3. Screenshot of the simulation results showing context (Φ, Ψ, Ω)–CS (T) combined associative strength during the 3 test trials of a renewal design in Groups AAA, AAB, ABA, and ABC. Simulation parameters: $\lambda = 1$; $\beta+ = 0.5$; $\beta- = 0.45$; $\alpha(T) = 0.4$; $\alpha(\Phi) = 0.25$; $\alpha(\Psi) = 0.25$; $\alpha(\Omega) = 0.25$; number of conditioning trials = 10;

number of extinction trials = 10; number of test trials = 3; ITI/CS ratio = 3. Checked boxes below the figure legend indicate the selected group and corresponding cues.

Figure1
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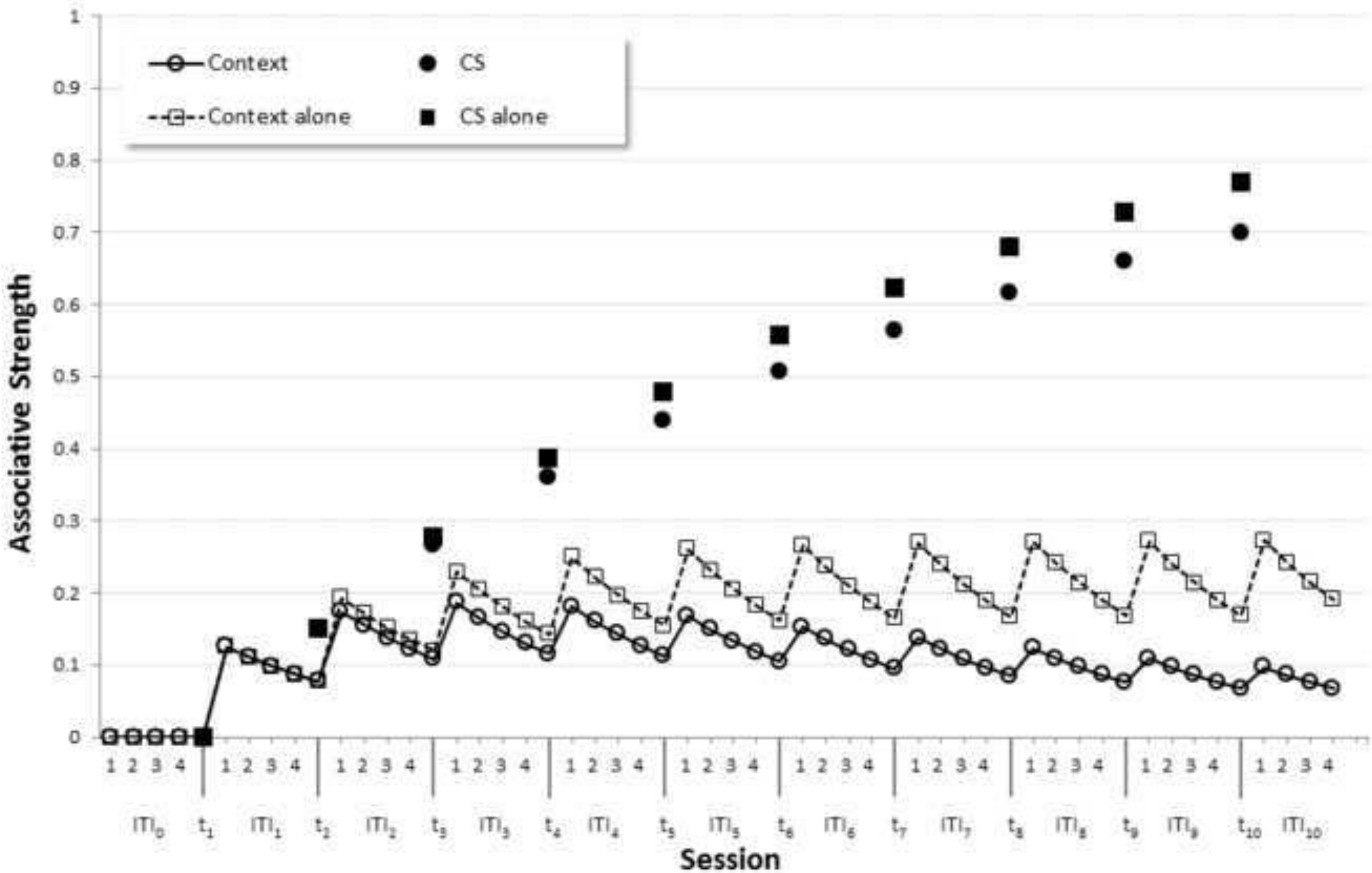

Figure2

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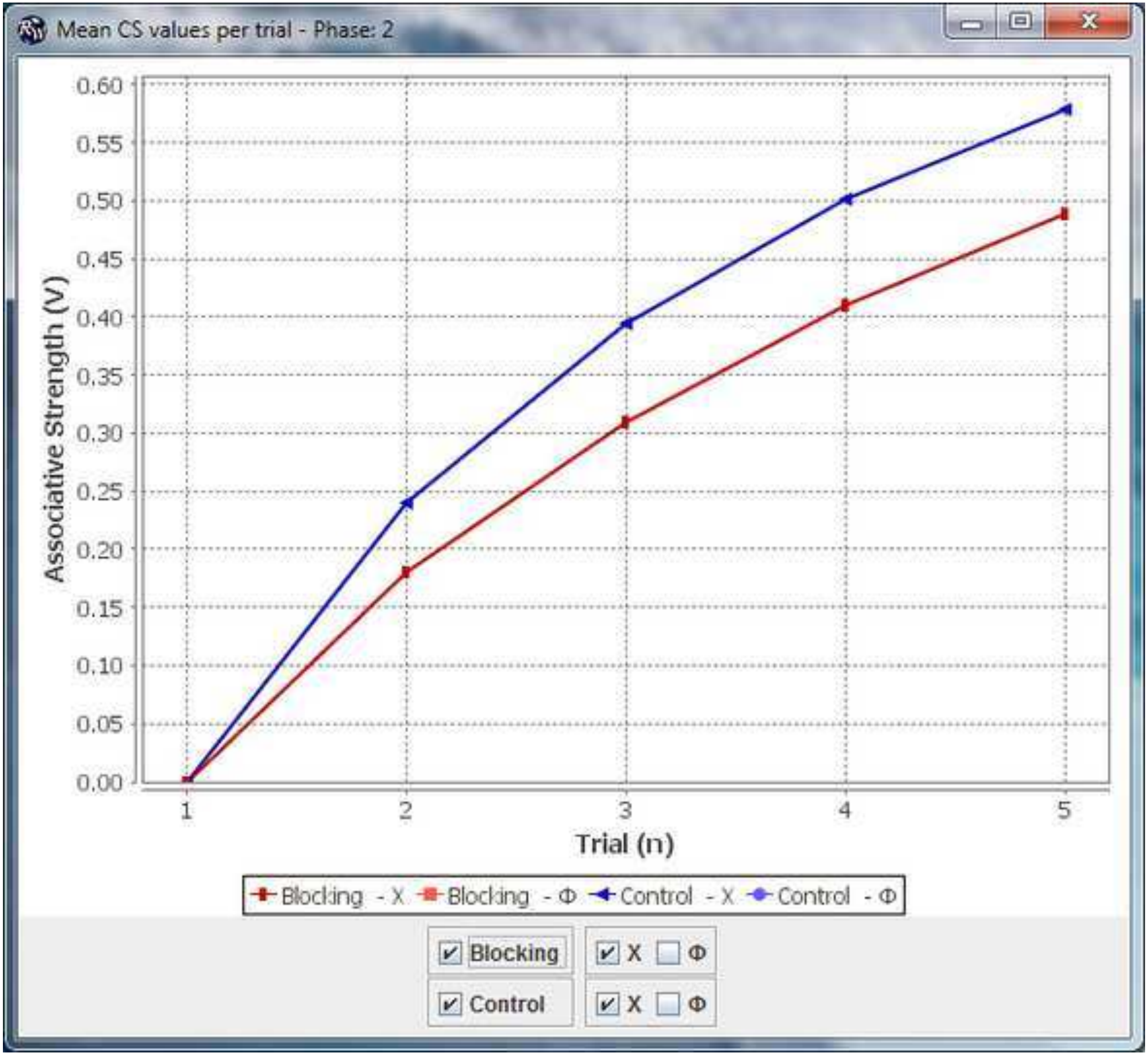

Figure3
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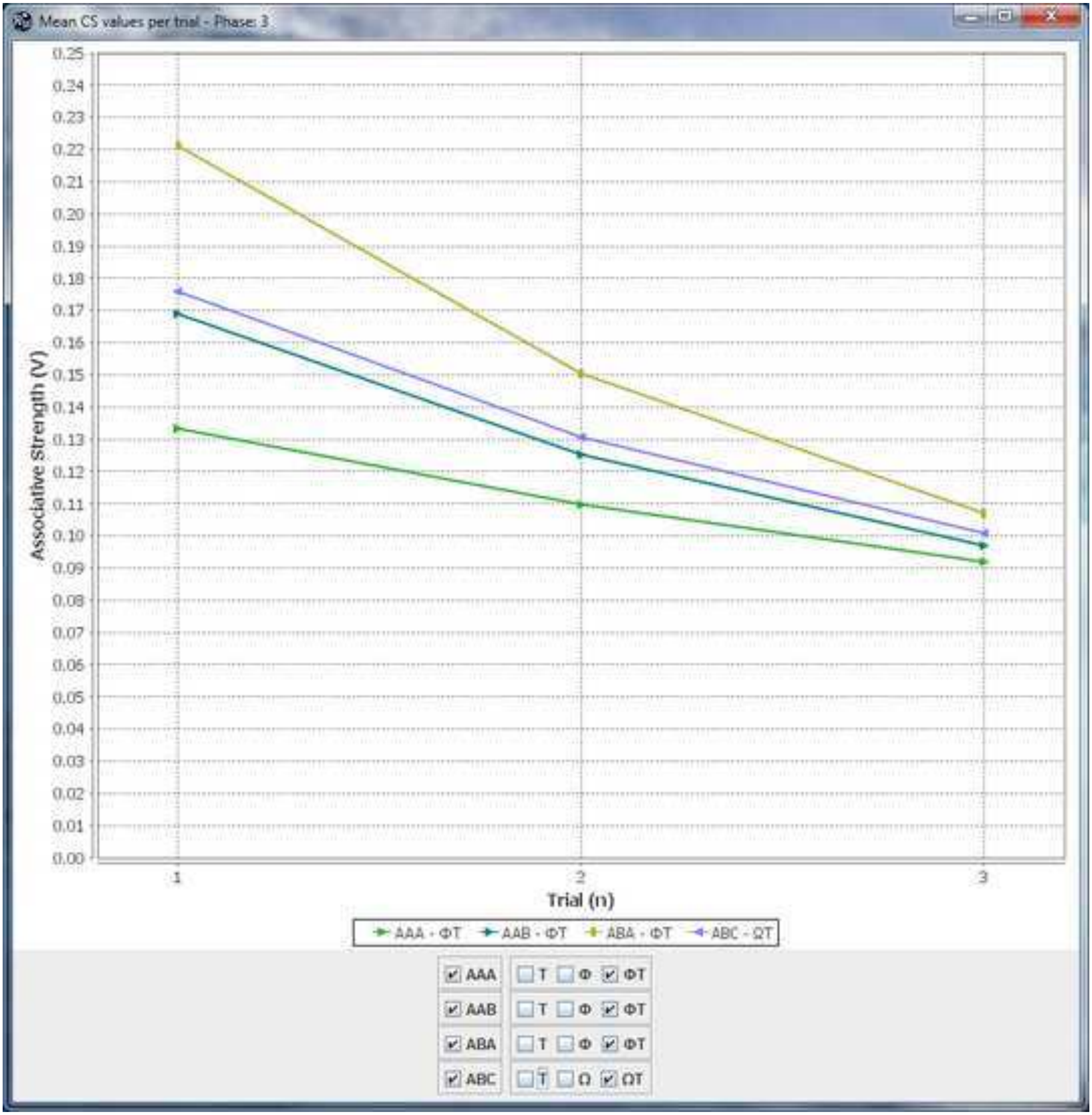

Dear Editor,

There are no conflicts of interest.

Dr Esther Mondragón and Dr Eduardo Alonso