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A NOTE ON MEASURING RECURRENCE

UNA NOTA SOBRE LE MEDICIÓN DE LA RECURRENCIA

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Abstract

Previously reinforced, and later extinguished, responding recurs when environmental conditions change. When studying recurrence, its magnitude (i.e., how much responding recurs) can be assessed by means of absolute and relative measures. These measures, however, highlight different aspects of recurrence that, if not taken into account, may lead to ambiguous interpretations of results. In the present article, first, absolute and relative measures of recurrence are described. Next, interpretations of hypothetical results are presented to illustrate that these measures provide different, but complementary, information about recurrence. That is, absolute response rates in the Test phase and response rates in the Test phase expressed as a proportion of response rates in the immediately preceding phase index how much responding recurs after undergoing extinction. On the other hand, response rates in the Test phase expressed as a proportion of response rates in the Training phase index how closely responding approaches its rate when previously reinforced. Considering the different, but complementary, information provided by each measure

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might lead to more precise descriptions and interpretations of empirical findings in the experimental analysis of recurrence.

Keywords: recurrence, reinstatement, renewal, resurgence, measurement, absolute measures, relative measures

Resumen

Las respuestas que fueron previamente reforzadas y posteriormente extinguidas, recurren cuando las condiciones ambientales cambian. Cuando se estudia la recurrencia, su magnitud (i.e., qué tanto recurre la respuesta) puede determinarse por medio de medidas absolutas y relativas. Estas medidas, sin embargo, resaltan diferentes aspectos de la recurrencia que, si no se toman en consideración, puede dar lugar a interpretaciones ambiguas de los resultados. En el presente artículo, primero se describen las medidas absolutas y relativas de la recurrencia. Posteriormente, se presentan interpretaciones de resultados hipotéticos para ilustrar que estas medidas proveen información diferente, pero complementaria, de la recurrencia. Esto es, las tasas de respuesta absolutas en las fases de Prueba y las tasas de respuesta en la fase de Prueba expresadas como una proporción de las tasas de respuesta en la fase precedente inmediata, son un índice de cuanto recurre la respuesta después de la extinción. Por otro lado, las tasas de respuesta en la fase de prueba expresadas como una proporción de las tasas de respuesta durante la fase de Entrenamiento son un índice de qué tanto se acercan las respuestas a su tasa cuando se reforzaron previamente. Considerando la información diferente, pero complementaria, que provee cada medida, puede resultar en descripciones e interpretaciones más precisas de los hallazgos empíricos en el análisis experimental de la recurrencia.

Palabras clave: recurrencia, restablecimiento, renovación, resurgimiento, medición, medidas absolutas, medidas relativas

Previously reinforced, and later extinguished, responding often recurs when environmental conditions change. This occurs, for example, (a) when reinforcers are delivered response independently after the target response has been extinguished (Reid, 1958); (b) when the stimulus context in effect during extinction of the target response changes (Bouton, Todd, Vurbic & Winterbauer, 2011); and (c) when currently reinforced, alternative responding also is extinguished (Epstein, 1983, 1985). Recurrence of the target response in (a), (b) and (c) is labeled, respectively, reinstatement, renewal and resurgence (for reviews, see Lattal & St. Peter

Pipkin, 2009; Marchant, Li & Shaham, 2013; Pritchard, Hoerger & Mace, 2014, respectively).

When studying recurrence, its magnitude (i.e., how much responding recurs) has been assessed using both absolute (i.e., absolute response rates) and relative measures (i.e., response rates as a proportion of responding in preceding phases; e.g., Berry, Sweeney, & Odum, 2014; da Silva, Cançado & Lattal, 2014; da Silva, Maxwell & Lattal, 2008; Fujimaki, Lattal, & Sakagami, 2015; Podlesnik & Shahan, 2009, 2010). These two types of measures, however, may lead to inconsistent descriptions of the magnitude of recurrence. For example, when comparing recurrence between components of concurrent (da Silva et al., 2008) or multiple (Fujimaki et al., 2015) schedules of reinforcement, the magnitude of recurrence might be greater in one than in the other component when an absolute, but not when a relative measure, is used. Also, as suggested in the present article, whether recurrence of differential magnitude between schedule components is obtained depends on how this relative measure is calculated.

In the present article, first, absolute and relative measures of recurrence are described. Next, interpretations of hypothetical results expressed in absolute and relative measures are presented to illustrate how different (but complementary) information about recurrence is provided by these measures. Finally, it is argued that considering the different, but complementary, information provided by each measure might lead to more precise descriptions and interpretations of empirical findings in the experimental analysis of recurrence.

Absolute and Relative Measures of Recurrence

Absolute and relative measures of recurrence will be described and interpreted in this article considering hypothetical data obtained from a resurgence procedure (the description and interpretation of such hypothetical data would be similar if other recurrence phenomena, such as reinstatement and renewal, were being studied). It is assumed that these data have been obtained in an experiment with rats by using a two-component multiple schedule of reinforcement in each phase of a three-phase procedure. Multiple and concurrent schedules of reinforcement are commonly used to assess recurrence within subjects as a function of differential reinforcement conditions between schedule components and across phases (e.g., da Silva et al., 2008; Fujimaki et al., 2015; Kinkaid, Lattal, & Spence, 2015; Podlesnik & Shahan, 2009). It should be noted that the information provided by absolute

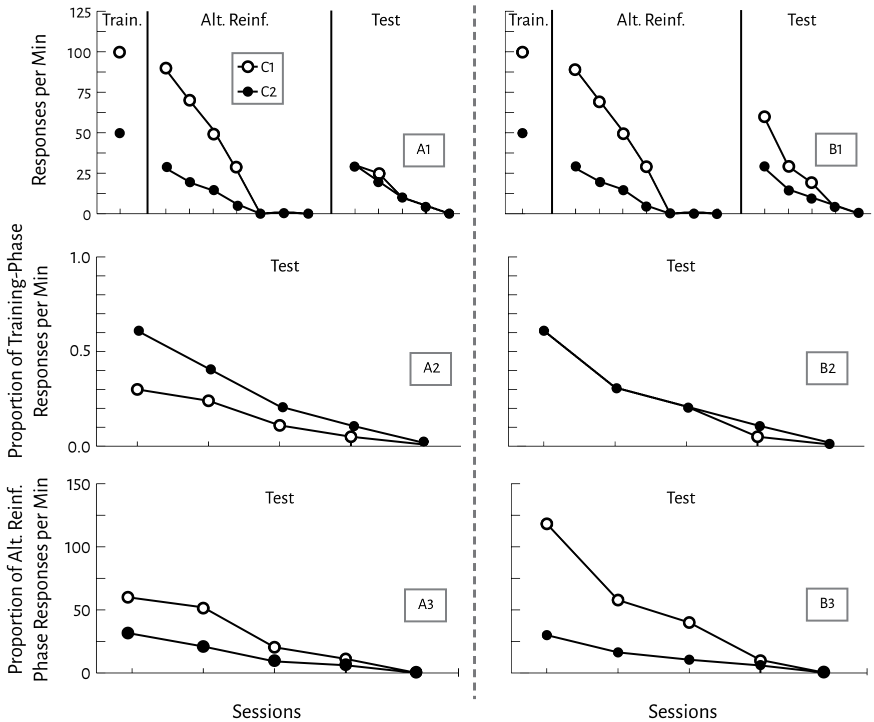

Figure 1. Hypothetical data from an experiment on resurgence in which a two-component multiple schedule was in effect across phases. The upper graphs (A1 and B1) show target-response rates (responses per min) in each schedule component in the last session of the Training phase, and each session of the Alternative Reinforcement and Test phases. The middle (A2 and B2) and bottom (A3 and B3) graphs show target-response rates in the Test phase as a proportion of, respectively, target-response rates in the last session of the Training phase and in the last session of the Alternative Reinforcement phase. Open and closed circles represent Component 1 (C1) and Component 2 (C2) respectively.

and relative measures as described in the present article is independent of the experimental design (i.e., within- or between-subjects) and the scale used to present data (e.g., absolute, proportional, or logarithmic).

In this hypothetical experiment, in the Training phase, the target response (e.g., left-lever press) was reinforced in one component (C1) on a variable-interval (VI) 30-s and, in the other component (C2), on a VI 120-s schedule. In the Alternative Reinforcement phase, reinforcers for the target response were discontinued and an alternative response (e.g., right-lever press) was reinforced on a VI 60-s schedule in each schedule component. In the Test phase, reinforcers for the alternative response also were discontinued. Resurgence is defined as the recurrence of the target response during the Test phase compared to its occurrence in the terminal sessions of the Alternative Reinforcement phase or the Training phase (da Silva et al., 2008; Doughty, da Silva & Lattal, 2007; Lieving & Lattal, 2003; Podlesnik & Shahan, 2009, 2010).

Figure 1 shows two hypothetical data sets (A, left graphs, and B, right graphs) that could result from such a hypothetical experiment (only target responding is represented in this figure as the focus of this article is to show how different measures of target responding provide different information about recurrence). The upper graphs (A1 and B1) show responding in each multiple-schedule component expressed as an absolute measure (responses per min) during the last session of the Training phase, and each session of the Alternative Reinforcement and Test phases (the data for the Training and Alternative-Reinforcement phases, but not the data from the Test phase, are the same in Graphs A1 and B1). The middle and bottom graphs show target-response rates in each schedule component during the Test phase as relative measures: As a proportion of response rates in the last session of the Training phase (A2 and B2) and as a proportion of response rates in the last session of the Alternative Reinforcement phase (A3 and B3).

Table 1 shows the actual values used to construct each graph in Figure 1 (absolute response rates in each component are presented for the last session of the Training and Alternative Reinforcement phases, and for each session of the Test phase). Note that response rates were different between multiple-schedule components in the Training and the Alternative-Reinforcement phase. In the Training phase, response rate (100 responses per min) was higher in C1 than in C2 (50 responses per min). In the last session of the Alternative-Reinforcement phase, response rate (1 response per min) was higher in C2 than in C1 (0.5 responses per min).

These three measures of resurgence (absolute response rates, proportion of Training-phase response rates and proportion of Alternative-Reinforcement phase response rates) and their interpretations are described below. One measure is not necessarily better than the others and each might be useful. But in assessing resurgence, it might be important to consider the information each measure provides.

Absolute Measure: Response Rates

The most common practice is to report absolute measures (e.g., responses per min) of resurgence. Graphs A1 and B1 of Figure 1 show different absolute rates of

Table 1.

Hypothetical Data shown in Figure 1

Hypothetical data: Figure 1 – Graphs A1, A2 and A3							
Phase	Session	Responses per Min		Prop. of Training Phase Responses per Min		Prop. of Alt. Reinf. Phase Responses per Min	
		A1		A2		A3	
		C1	C2	C1	C2	C1	C2
Training	Last	100	50	–	–	–	–
Alt. Reinf.	Last	0.5	1	–	–	–	–
Test	1	30	30	0.30	0.60	60	30
	2	25	20	0.25	0.40	50	20
	3	10	10	0.10	0.20	20	10
	4	5	5	0.05	0.10	10	5
	5	1	1	0.01	0.02	2	1
Hypothetical data: Figure 1 – Graphs B1, B2 and B3							
		B1		B2		B3	
		C1	C2	C1	C2	C1	C2
Training	Last	100	50	–	–	–	–
Alt. Reinf.	Last	0.5	1	–	–	–	–
Test	1	60	30	0.60	0.60	120	30
	2	30	15	0.30	0.30	60	15
	3	20	10	0.20	0.20	40	10
	4	5	5	0.05	0.10	10	5
	5	1	1	0.01	0.02	2	1

Note. Absolute response rates and response rates as a proportion of the last session of the Training and Alternative Reinforcement phases, in Components 1 – C1 – and 2 – C2.

responding in each multiple-schedule component in the Training phase. Each graph also shows that, in the Alternative Reinforcement phase, response rates decreased across sessions in both components and were near zero, but were higher in C2 than in C1 during the last session of this phase (see Table 1).

Resurgence occurred in both multiple-schedule components. In Graph A1, response rates were similar in both schedule components across sessions of the Test phase. In Graph B1, response rates were higher in C1 than in C2 during the first three sessions of the Test phase, but did not differ across components in the remaining sessions of this phase. Thus, the magnitude of resurgence was similar between components in Graph A1 and greater in C1 than in C2 in Graph B1 in the first three sessions of the Test phase.

Analyses of resurgence based on absolute response rates in the Test phase, however, do not take into account the differences in target-response rates between multiple-schedule components that might occur in previous phases. When response rates are different between multiple-schedule components in the Training and Alternative Reinforcement phases, a useful approach is to measure target responding in the Test phase as a proportion of target-response rates in those phases (e.g., Nevin & Shahan, 2011; Podlesnik & Shahan, 2010; Shahan & Sweeney, 2011). Thus, the magnitude of resurgence (and other recurrence phenomena, Berry et al., 2014; Podlesnik & Shahan, 2009) also has been assessed when response rates are expressed as a proportion of Training or Alternative-Reinforcement phase response rates.

Relative Measure: Proportion of Training-Phase Response Rates

Graphs A2 and B2 in Figure 1 show response rates in each schedule component during each session of the Test phase as a proportion of response rates in the last session of the Training phase. Data points were generated by dividing response rates in a component during each session of the Test phase by the response rate in that same component in the last session of the Training phase.

In Graph A2, during the first four sessions of the Test phase, responding as a proportion of the Training phase was greater in C2 than in C1. These data suggest the magnitude of resurgence was greater in C2 than in C1 (i.e., that "more resurgence" occurred in C2 than in C1). In Graph B2, in the Test phase, responding as a proportion of the Training phase was equal in the two components, except during the fourth session, when response rate was slightly higher in C2 than in C1. These data suggest the magnitude of resurgence in both components was similar. The hypothetical results shown in Graphs B1 and B2 are not without precedence in the recurrence literature. da Silva et al. (2008; Experiments 1 and 2), for example, reported differential resurgence between components of a two-component concurrent schedule when data were presented as absolute measures (responses per min) but not when responding was expressed as a proportion of Training-phase response rates. With the latter analysis, their data resembles those presented in Graphs B1 and B2.

But what information is provided about resurgence when Test-phase responding is expressed as a proportion of Training-phase response rates? In Graph A2, in the first session of the Test phase, responding as a proportion of the Training phase was 0.3 and 0.6 in C1 and C2, respectively. These values show that response rates in C1 and C2 recovered 30% and 60%, respectively, of the respective response rates during the last session of the Training phase. Because recovery of previous response-rate values was higher in C2 than C1, it might be said that the magnitude of resurgence was greater in C2 than in C1. A similar interpretation can be made of the data in Graph B2. In the first session of the Test phase, target response rates recovered, in both components, 60% of their values in the last session of the Training phase, and thus, it might be said that the magnitude of resurgence was equal between components when responding is expressed as a proportion of Training-phase response rates. But more specifically, measures of the proportion of Training-phase response rates offer evidence about how closely responding in the Test phase approaches the rate at which it occurred in the Training phase. For example, if response rates in the Test phase, expressed as a proportion of Training phase response rates, are 1.0, then responding recovered to its Training-phase level.

If one wants to assess how much response rates increased in the Test phase relative to the last sessions of the Alternative-Reinforcement phase, especially when response rates in the terminal sessions of the Alternative-Reinforcement phase differ between schedule components, the data can be examined as absolute measures (Graphs A1 and B1) or, more precisely, as a proportion of Alternative-Reinforcement phase response rates.

Relative Measure: Proportion of Alternative-Reinforcement Phase Response Rates

Graphs A3 and B3 in Figure 1 show response rates in each multiple-schedule component during the Test phase as a proportion of response rates in those components during the last session of the Alternative Reinforcement phase. These data were calculated by dividing response rates in a component in each session of the Test phase by response rates in the same component in the last session of the Alternative Reinforcement phase. Differently from the analysis in terms of proportion of Training-phase response rates (Graphs B1 and B2), this measure indicates how much, proportionally, response rates in the Test phase increase relative to the Alternative Reinforcement phase. Note, that response rates in both multiple schedule components are slightly greater than zero in the last session of the Alternative Reinforcement phase (see Table 1), which allows the calculation of proportions without any additional transformation of the data. If response rates in this session were zero, to generate measures of proportion of Alternative-Reinforcement phase responding, one could add a constant (e.g., 1) to each response rate measure in the last session of the Alternative Reinforcement phase and each session of the Test phase in which recurrence occurred (i.e., this constant would not be added to Test-phase sessions in which response rates were zero or were not higher than those in the last sessions of the Alternative Reinforcement phase). This would allow calculation of the proportions and would not change the general pattern of results expressed as a proportion of Alternative-Reinforcement phase responding (see Okouchi, 2015, for an example of similar type of data transformation in a study of resurgence with humans).

Graph A3 shows that, in the first Test-phase session, response rates in C1 and C2 increased to a value that was 60 and 30 times higher, respectively, than response rates in each component during the last session of the Alternative Reinforcement phase. Thus, the magnitude of resurgence would be described as greater in C1 than in C2 in this and the subsequent three sessions of the Test phase. Compared to Graph A3, the data in Graph B3 also show a greater increase in response rates relative to the Alternative Reinforcement phase in C1 than in C2 in the first three sessions of the Test phase. Thus, based on the data of Graphs A3 and B3, one would conclude that the magnitude of resurgence was greater in C1 than in C2, but the differences between components were more extreme in the data of Graph B3 than A3.

The data in Graphs A2 and A3, and B2 and B3, are not necessarily incompatible. They simply highlight different analyses of recurrence. As stated previously, when Test-phase response rates are expressed as a proportion of Training phase response rates (Graphs A2 and B2), one shows how much responding approaches the rate at which it occurred when previously reinforced (i.e., during the Training phase). When Test-phase response rates are expressed as a proportion of Alternative-Reinforcement phase response rates, one shows how much responding increases relative to its rate after undergoing extinction.

Conclusion

Absolute and relative measures were described and interpreted in the present article considering hypothetical results of an experiment on resurgence. As noted previously, each of these measures would be similarly interpreted if other recurrence phenomena, such as renewal and reinstatement (e.g., Berry et al., 2014; Podlesnik & Shahan, 2009) were being studied. That is, the information provided by each measure is not particular to one recurrence phenomenon (i.e., resurgence). The choice of reporting absolute and/or relative measures should be based on the procedure and, especially, on the results obtained in each phase of a three-phase procedure used in experimental analyses of recurrence.

An absolute measure of recurrence would suffice, for example, in two situations. First, if single schedules of reinforcement were used across phases (e.g., in a resurgence experiment, when target and alternative responding are maintained in the Training and Alternative-Reinforcement phases on a VI 30-s schedule of reinforcement). Second, considering the procedure used in the hypothetical experiment described in this article, if response rates in the Training phase are equal between multiple-schedule components, and responding is reduced to zero or near zero and is the same in each component during the Alternative Reinforcement phase. When response rates differ between schedule components in these phases, however, relative measures might be useful in assessing the results.

The relative measures described in the present article allow the assessment of the magnitude of recurrence, but they highlight different information. The increase in response rates relative to the Alternative-Reinforcement phase might be different between components of a multiple schedule (Figure 1, Graphs A3 and B3), but in each component response rate might have increased to different (Graph A2) or similar (Graph B2) levels than those observed in the Training phase. In addition, the absolute measure may differ from both relative measures (compare Graph A1 with Graphs A2 and A3), or may be consistent with one of the relative measures (see Graphs B1 and B3).

Because both relative measures previously described provide information that qualify changes in recurrence magnitude, it might be useful to report each of these measures and to explore how they complement each other in the experimental analysis of responding that recurs after it has been extinguished (Lattal, St Peter & Escobar, 2013; Vurbic & Bouton, 2014; see especially Lattal & Wacker, 2015).

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