International Journal of Psychology and Psychological Therapy 2004, Vol. 4, Nº 3, pp. 587-603

The Unfolding of the Relational Operant: A Real-time Analysis Using Electroencephalography and Reaction Time Measures

Bryan Roche*[1], Conor Linehan[1], Tomás Ward[1], Simon Dymond[2], and Ruth-Anne Rehfeldt[3]

[1]*National University of Ireland, Maynooth, Ireland;* [2]*APU, Cambridge, UK;* [3]*Southern Illinois University, USA*

Abstract

The current study attempted to capture in real time the unfolding of the relational operant using electroencephalography (EEG) and reaction time measures. Participants were exposed to relational pretraining to establish the contextual cues of Same and Opposite for two arbitrary stimuli. These cues were then used to establish a series of contextually controlled discriminations in order to create a simple relational network among a series of arbitrary stimuli. During the test for derived relations of Same and Opposite, EEG and reaction time measures were recorded for each individual test task during the acquisition of a stable derived relational response pattern. Participants were then exposed to an identical set of relational training and testing tasks with the important difference that an entirely different set of stimuli was used. EEG and reaction time measures were again recorded during the relational test phase. Results showed that reaction times decreased for all subjects across successive test tasks and from the first to the second stimulus set. EEG data also suggested that there was increasingly less higher cognitive activity during the derivation of successive stimulus relations within and across stimulus sets. Taken together these findings provide support for the idea that derived relational responding can be viewed as an operant activity that both develops and generalizes.

Key words: Relational Frame Theory, Electroencephalography, Multiple exemplar training, Stimulus equivalence.

Resumen

El desarrollo de la operante relacional: Un análisis en tiempo real mediante el empleo de electroencefalografía y medidas de tiempo de reacción. El presente estudio es un intento de capturar en tiempo real el desarrollo de la operante relacional mediante el uso de electroencefalografía (EEG) y de medidas de tiempo de reacción. Los participantes fueron expuestos a un pre-entrenamiento relacional para establecer las claves contextuales Igual y Opuesto con dos estímulos arbitrarios. Estas claves fueron empleadas posteriormente para establecer una serie de discriminaciones condicionales contextualmente controladas para crear una red relacional simple entre varios estímulos arbitrarios. En el test de relaciones derivadas de Igual

* Correspondence concerning this article should be sent to Bryan Roche, Department of Psychology, National University of Ireland, Maynooth, Ireland. E-mail: Bryan.T.Roche@may.ie

y Opuesto se tomaron medidas de EEG y tiempo de reacción en cada tarea particular, simultáneamente a la adquisición de un patrón estable de derivación de relaciones. Posteriormente los participantes volvieron a pasar por un conjunto idéntico de tareas de entrenamiento y evaluación de relaciones, con la diferencia de que para ello se utilizó un conjunto de estímulos completamente diferente. Al igual que antes se tomaron medidas de EEG y tiempo de reacción de manera simultánea al desarrollo de la tarea relacional. Los resultados muestran que los tiempos de reacción disminuyeron para todos los sujetos a lo largo de las sucesivas tareas de evaluación, y del primer al segundo conjunto de estímulos. Los datos de EEG también sugieren que la actividad cognitiva superior va disminuyendo durante la derivación de relaciones sucesivas, tanto dentro de cada conjunto de estímulos como entre conjuntos. Estos datos, en general, viene a apoyar la idea de que el comportamiento relacional derivado es una actividad operante que se desarrolla y generaliza.

Palabras Clave: Teoría del Marco Relacional, electroencefalografía, entrenamiento en múltiples ejemplos, equivalencia de estímulos.

The phenomenon of derived relational responding is now familiar to many teachers and practitioners of behavior analysis. The methodological details of this phenomenon are dealt with in other papers in this series and it is not our intention to reconsider definitional or procedural matters regarding relational activity. Instead we will report on an empirical study that examines closely the operant nature of relational responding.

The idea that derived relational responding constitutes generalized operant activity is pivotal to Relational Frame Theory (RFT; Hayes, Barnes-Holmes, & Roche, 2001). RFT suggests that young children are routinely exposed to social situations in which explicit reinforcement is available for responding appropriately across a large number of word-object and object-word sequences. For example, children are often engaged by caregivers in object-naming games wherein the child must both name an object appropriately and orient towards the object when given the name (e.g., What is this? Show me the car.) Following a sufficient number of explicitly reinforced exemplars of object-name and name-object relations, a child will be able to reverse a novel name-object relation without reinforcement (see Barnes-Holmes & Barnes-Holmes, 2000. See also Hayes, Fox, Gifford, Wilson, Barnes-Holmes, & Healy, 2001; Hayes, Gifford, & Wilson, 1996). The precise details of the history required to produce derived relational responding are not crucial to the RFT position on the generalized operant. Rather they are posed as important empirical questions (see Hayes & Wilson, 1996).

Two operant features of derived relational responding that are of particular concern in the present study are its development and generalization to novel stimuli. Limited research has been reported that demonstrates the sensitivity of derived relational responding to reinforcement contingencies (e.g., Healy, Barnes-Holmes, & Smeets, 1998; 2000). In addition some longitudinal research has tracked the emergence of derived relational responding in young children (e.g., Barnes-Holmes, Barns-Holmes, Roche, & Smeets, 2001a; Barnes-Holmes, Barnes-Holmes, Roche, & Smeets, 2001b; Lipkens, Hayes, & Hayes, 1993). However, no study to date has examined the emergence of derived relational responding in a trial-by-trial analysis across multiple stimulus sets in a discrete laboratory study. Before we outline the current study, however, we must first consider the issue of dependent measures of relational responding.

In order not to confuse the nature of relational phenomena with the measures of relational responding frequently employed, it is important to utilize a wide variety of procedures for evaluating the nature and strength of derived relations (Dymond & Rehfeldt, 2001; L. Hayes, 1992). Relying too closely on any one measure may occlude important discoveries regarding the nature of derived stimulus relations. For instance, several authors have suggested that the development of new measures of derived relational repertoires, other than those based on matching-to-sample and the percentage correct criterion, has been restricted by both the explanatory concept of stimulus classes (e.g., Hayes & Barnes, 1997) and the idea that equivalence is widely considered as a basic stimulus function (see Barnes-Holmes, Hayes, Dymond, & O'Hora, 2001).

Although 'percentage correct' is by far the most common measure of derived relational responding, other creative measures have been reported in the literature (see Dymond & Rehfeldt, 2003). Some researchers (i.e., Dube, Green, & Serna, 1992; Kennedy, 1991) have employed the number of training trials required for particular relations to emerge as a measure, while others have examined participant estimation of reinforcer probability (i.e., Pilgrim & Galizio, 1996). Response latency has also been employed in a number of studies. For example, Bentall, Dickins, and Fox (1993) examined response latency in a study which found that participants took longer to respond to trials for derived relations than to trials for directly trained relations (see also O'Hora, Roche, Barnes-Holmes, & Smeets, 2002; Spencer & Chase).

In one study, Steele and Hayes (1991) found that participants responded more quickly to derived Same relations than Opposite relations. These researchers suggested that this finding reflected the differing levels of complexity of Same and Opposite relations (i.e., two Same relations combine to form a further Same relation, whereas two Opposite relations combine to form a relation of another type). O'Hora, et al. (2002) found that reaction times at the level of mutual entailment for Same, Opposite, More than, and Less than decreased across trials and across an additional stimulus set. That is, derived relational responses increased in speed (i.e., the inverse of latency) from trial-to-trial. Moreover, on a novel stimulus set participants derived relations more quickly from the very first test trial, illustrating a generalization of derived relational responding.

In recent years it has also become possible to measure derived relational responding at the physiological level. For example, Dickins, Singh, Roberts, Burns, Downes, Jimmieson, and Bentall (2001) employed functional magnetic resonance imaging (fMRI) to analyze brain activity during a stimulus equivalence task. Response accuracy on equivalence tests was significantly correlated with left lateralization of the dorsolateral prefrontal cortex, an area of the brain associated with language. Furthermore, activity in the Broca's area, an area understood to be involved in naming (Pinel, 2000), was correlated only with verbal fluency tasks and not with deriving equivalence relations. These researchers suggested that these findings may “shed light on possible underlying or mediating processes involved in stimulus equivalence” (p. 2).

While fMRI offers the spatial resolution to identify regions of the brain that are active under various stimulus conditions, it lacks the temporal resolution to reliably track changes from trial to trial (Davidson, Jackson, & Larson, 2000). Electroencephalography (EEG) represents one measure that provides excellent temporal resolution for the analysis of ongoing streams of behavior and is cheap and easy to use. The EEG signal is derived from summated post-synaptic potentials. This measurement represents a direct and non-invasive measurement of electrical brain activation and has been correlated with both verbal (e.g., Elger, Grunwald, Lehnertz, Kutas, Helmstaedter, Brockhaus, Van Roost, & Heinze, 1997) and nonverbal (e.g., Fisch, 1999) indicators of body state.

DiFiore, Dube, Oross, Wilkinson, Deutsch, and McIlvane (2000) used measures of Event Related Potentials (ERPs; a modern development of EEG technology) to analyze brain wave functions during a stimulus equivalence task (see also Deutsch, Oross, S. III, DiFiore, & McIlvane, 2000). Specifically, these researchers report on the utility of ERPs measures in distinguishing between subjects’ responses to equivalently related and unrelated pairs of stimuli presented together. These researchers also seem to share Dickens et al.’s interest in identifying processes underlying the stimulus equivalence effect. Specifically, they state, “…at the neural level one can detect evidence of equivalence class formation even prior to the tests” (p. 3).

Interestingly, Deutsch et al. also failed to harness the temporal resolution of the ERPs measure for a real-time moment-to-moment analysis of derived relational responding. Moment-to-moment measures of derived relational responding at the neural level would help to the shift the focus of research away from the identification of potentially mentalistic causes of behavior (i.e., brain activation) and emphasize the traditional behavioral features of repertoire acquisition and generalization. Thus, in the current study electroencephalography and response latency measures were employed simply as one of several possible concurrent measures of derived relational responding. The use of these measures does not suggest an interest in explanatory mechanisms other than the operant history of the participants.

In the current study, EEG was recorded during the acquisition of a derived relational responding repertoire across two stimulus sets in succession. EEG activity in the alpha band was tracked from trial to trial and across stimulus sets in an attempt to capture in real time the effects of practice on derived relational skills. Reaction time was recorded concurrently for the same purpose.

Method

Participants

Eight male and eleven female participants were recruited through personal contacts. All participants were undergraduate students aged between 18 and 22 years.

Apparatus

Participants were seated in a comfortable reclining chair, facing a Macintosh Performa 6300 Power PC computer. All tasks were presented on the computer's 15" screen. The presentation of training and testing tasks and the recording of participants' responses and response latencies was controlled by software written using the experiment generation software application Psyscope 1.2.5 (Cohen, MacWhinney, Flatt, & Provost 1993; see also Roche & Dymond, 2003; Roche, Stewart, & Barnes-Holmes 1999). The temporal accuracy of the PsyScope software is 1ms. However, the temporal accuracy of the Macintosh 68000 processor used in this study is 16ms. Thus, recorded response latencies are accurate to within 16ms.

A standarized 12-electrode EEG cap was employed to connect silver-silver chloride (AgAgCl) EEG electrodes to the participants' scalps. Three electrodes were attached to the T3, P3, and Fz locations, respectively, using the international 10-20 system of electrode placement (see Fisch, 1999). Fz and T3 were used as electrode placement positions as they are understood to be active during verbal activity. P3 was used as an EEG recording reference point as it is not understood to be involved in verbal activity at the level of the brain. Standard high-electrolyte EEG gel was used to secure the contact points between the electrodes and the participants' scalps. An elastic chest harness was also used to secure the cap.

The EEG signal was amplified using a Lafayette Instruments biopotential amplifier (Model 70702), which was connected to a 16-channel Lafayette Instruments *Datalab 2000* polygraph, controlled by National Instruments *BioBench* software. The acquisition and analysis software was run on a Dell Optiplex Gx110 PC with Pentium III processor. The EEG signal was filtered using a 50 Hz notch filter during acquisition (50Hz is the frequency of AC mains current in Ireland).

Event markers were created on the EEG record by a 5v pulse supplied by a *PsyScope Button Box* synchronously with each stimulus presentation and upon each response. Both the PsyScope application and the software used in this experiment can be downloaded from http://www.may.ie/academic/psychology/software.shtml

General Procedure

Upon fitting the electrode cap to a participant they were asked to remain perfectly still for the entire during of the experiment except when they were told that they could move by the experimenter (i.e., between training and testing phases). A computer keyboard was then placed on the participant's lap so that they could respond to each task on the keyboard with one hand only and with as little movement as possible. For this purpose, participants were asked to place their fingers on the response keys and to leave them there for the duration of the experiment (see Figure 1 for the configuration of the experimental room). Instructions were then presented to participants on the computer screen and the relational pretraining and testing, relational training, and relational testing phases were administered. Following the completion of this phase, participants were exposed to an identical procedure using a novel set of stimuli.

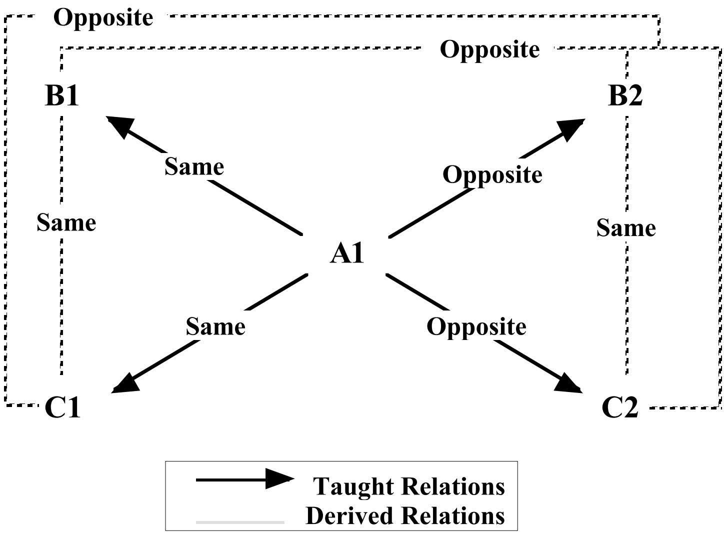

Figure 1. The taught and derived relations established during relational training and testing. Solid lines indicate trained relations. Hashed lines indicate derived relations examined during the test phase.

All tasks consisted of a contextual stimulus (!!!!!! or ??????) presented in the top third of the screen, a sample stimulus in the middle, and three comparison stimuli in the lower third of the screen. The position of comparison stimuli (left, middle, and right) was counter-balanced across trials. Participants responded by pressing the key on the keyboard that corresponded to the stimulus they wished to choose. For example, if the participant wished to choose the left comparison, they pressed the 'Z' key, the 'V' key corresponded to the middle comparison, and the 'M' key to the right comparison. Upon the choice of a comparison stimulus in all training trials, the screen cleared and was replaced by either the word 'Correct' or 'Wrong'. The feedback remained on the screen for 2.5s, after which it was immediately followed by the next trial. No feedback was provided during testing phases.

Relational Pretraining and Testing

The relational pretraining was designed to establish the functions of 'Same' and 'Opposite' for the arbitrary contextual stimuli '!!!!!!' and "??????', respectively. Sample and comparison stimuli for pretraining trials were related to one another along a physical dimension such as size, length, or shading. For example, one set of sample stimuli involved three squares, one of which was lightly shaded, one of which was moderately shaded, and one that was heavily shaded. Given the 'Same' contextual cue and a lightly shaded square as a sample, choosing the lightly shaded comparison constituted a correct response. However, in the presence of the 'Opposite' contextual cue, the heavily shaded box was the correct comparison.

In total, there were six problem sets, each consisting of four tasks. One block of pretraining consisted of two problem sets. More specifically, each of the four tasks from problem set 1were presented in quasi-random order until each had been presented twice (i.e., 8 trials). This procedure was then repeated for problem set 2 (i.e., 8 trials). Finally, the two sets (16 trials) were presented again in the same manner. In effect, a training block consisted of 32 training trials. Blocks were presented repeatedly, up to a maximum of four times, until participants produced 28 correct responses out of the total of 32.

Testing involved the presentation of two novel problem sets, 3 and 4. The four tasks from each problem set were presented only once in a quasi-random order (i.e., the four tasks from problem set 3 were presented in a random order, followed by the four tasks from problem set 4, again presented in a random order). Subjects were required to produce correct responses on every one of the 8 test trials. If a subject failed to produce 100% correct responding they were retrained on problem set 2 and 3. Participants were repeatedly exposed to this second training phase, up to a maximum of four times, until they produced 28 correct responses out of the total of 32. They were then exposed to a second testing phase consisting of problem set 4 and a novel set 5. The four tasks from each problem set were presented once in a quasi-random order. If a subject failed to produce 100% correct responding across the 8 trials they were retrained on problem set 3 and 4. Participants were repeatedly exposed to this third training phase, up to a maximum of four times, until they produced 28 correct responses out of the total of 32. They were then exposed to a third testing phase consisting of problem set 5 and a novel set 6. The four tasks from each problem set were presented once in a quasi-random order. If a subject failed to produce 100% correct responding they were dropped from the experiment.

Relational Training and Testing

Following relational pretraining, participants were exposed to relational training. The tasks employed were; Same/A1-[<u>B1</u>-B2-N1], Same/A1-[<u>C1</u>-C2-N2], Opposite/A1-[B1-<u>B2</u>-N1], and Opposite/A1-[C1-<u>C2</u>-N2], where all alphanumerics refer to three-letter nonsense syllables and underlined comparison stimuli indicate correct responses (see Figure 2). The actual stimuli used for the first stimulus set were; ZID, MEL, LEB, PAF, VEP, JOM, and CUG. The stimuli used for the second stimulus set were; LER JEP, TAL ROG, SOF, MAU, and VEK.

Training was conducted in blocks of 40 trials with each of the four tasks being presented ten times each in a quasi-random order. Feedback was given in the same manner as for pretraining tasks. Participants were required to respond with no more than one incorrect response on the last 24 trials in a block. If a participant failed to meet this criterion they were re-exposed to the training phase up to a maximum of three times (i.e., four in total).

Testing examined whether responding in accordance with the expected derived relations of Same and Opposite would emerge. The tasks used were; Same/B1-[C1-C2-N2], Same/B2-[C1-C2-N2], Opposite/B1-[C1-C2-N2], and Opposite/B2-[C1-C2-N2], where the underlined comparison stimuli indicate the correct choice. Testing was also conducted in blocks of 40 trials with each of the four tasks being presented ten times each in a quasi-random order. The same mastery criterion as used for training was applied.

Figure 2. The configuration of the experimental room. The polygraph and PC used for EEG acquisition are on the table to the foreground. The PsyScope Button Box sits to the rear of this table. In the background a participant wears the EEG cap , and sits comfortably in an easy-chair with the computer keyboard on her lap facing the Macintosh PC on which all tasks were presented.

When a participant passed the relational testing phase they were required to complete the entire training and testing process again with novel stimuli. Breaks of approximately one minute were provided to participants between all training and testing phases. To reduce the impact of fatigue participation was terminated if a participant failed to complete all phases of the study within two hours.

Results

Seven participants of the nineteen recruited demonstrated stable derived relational responding in accordance with the predicted relations. The performances of the remaining participants will not be discussed.

On the original stimulus set (Set 1), Participants 1, 2, and 3 met the relational training criterion on their first attempt. Participants 1 and 2 then passed relational testing immediately. Participant 3 failed the relational testing on the first attempt, and was re-exposed to training after which he immediately passed the testing phase. Participants 4, 5, 6, and 7 met the relational training criterion on their second attempt, then proceeded to pass the testing phase on their first attempt. On the second stimulus set Participants 1, 2, 4, 5, 6, and 7 passed relational training on their first attempt. Participant 3 passed on the second exposure. All participants passed the relational testing phase on their first attempt.

Table 1 shows the median response latencies of each participant during their first successful exposure to the relational testing phase on both the original (Set1) and novel (Set2) stimulus sets. The table shows that Participants 1, 2, 3, 4, 6, and 7 demonstrated a decrease in response latencies from the original set to the novel stimulus set. Figure 3 provides a graphic illustration of the change in response latencies trial to trial, for

Table 1. Median response latencies in milliseconds during the first successful exposure to the original (Set 1) and novel (Set 2) stimulus sets.

Participant	Set 1	Set 2
1	1914.5	1219
2	4097	1851.5
3	1946	1444
4	2985	2482.5
5	1213	1285.5
6	4379	3726.5
7	1462.5	800

Table 2. Median response latencies in milliseconds during the first and last quartiles of the first successful exposure to the original (Set 1) and novel (Set 2) stimulus sets.

Participant	First Quartile	Last Quartile
1	2395	998.5
2	8057.5	3636.5
3	2476	2107
4	4394.5	2925
5	1537.5	1065.5
6	4303	3642
7	2779	1198

both the original and novel stimulus sets.

Table 2 shows the median response latency for each participant during the first and last quartile of their first successful exposure to a relational testing phase. All participants demonstrated a decrease in median response latency from the first quartile to the final quartile of a relational testing block.

Figure 3 shows each participant's reaction time to each successive probe during their first successful exposures to the relational test using both the original (Set 1) and novel (Set 2) stimulus sets. One-way repeated measures analysis of variance (ANOVA) tests were conducted to examine the statistical significance of the response latencies changes across the original and novel stimulus sets. Participant 1 showed a mean decrease in response latency between the original stimuli set ($M= 3308.75$, $SD= 3454.2351$) and the novel stimuli set ($M= 1342.175$, $SD= 936.5584$). This effect was significant (Wilks' Lambda= 0.705, $F(1,39)= 16.313$, $p< 0.01$, multivariate eta squared= 0.295). Participant 2 also showed a mean decrease in response latency between the original stimuli set ($M= 5765.825$, $SD= 4417.5242$) and the novel stimuli set ($M= 2033.775$, $SD= 811.0035$). The difference was also significant (Wilks' Lambda= 0.557, $F(1,39)$=, $p<0.01$, multivariate eta squared= 0.443). Participant 6 showed a mean decrease in response latency between the original stimuli set ($M= 5633.125$, $SD= 3821.8337$) and the novel stimuli set ($M= 3825.825$, $SD= 1895.623$). This difference was significant (Wilks' Lambda= 0.824, $F(1,39)= 8.335$, $p< 0.01$, multivariate eta squared= 0.176). Participant 7 showed a mean decrease in response latency between the original stimuli

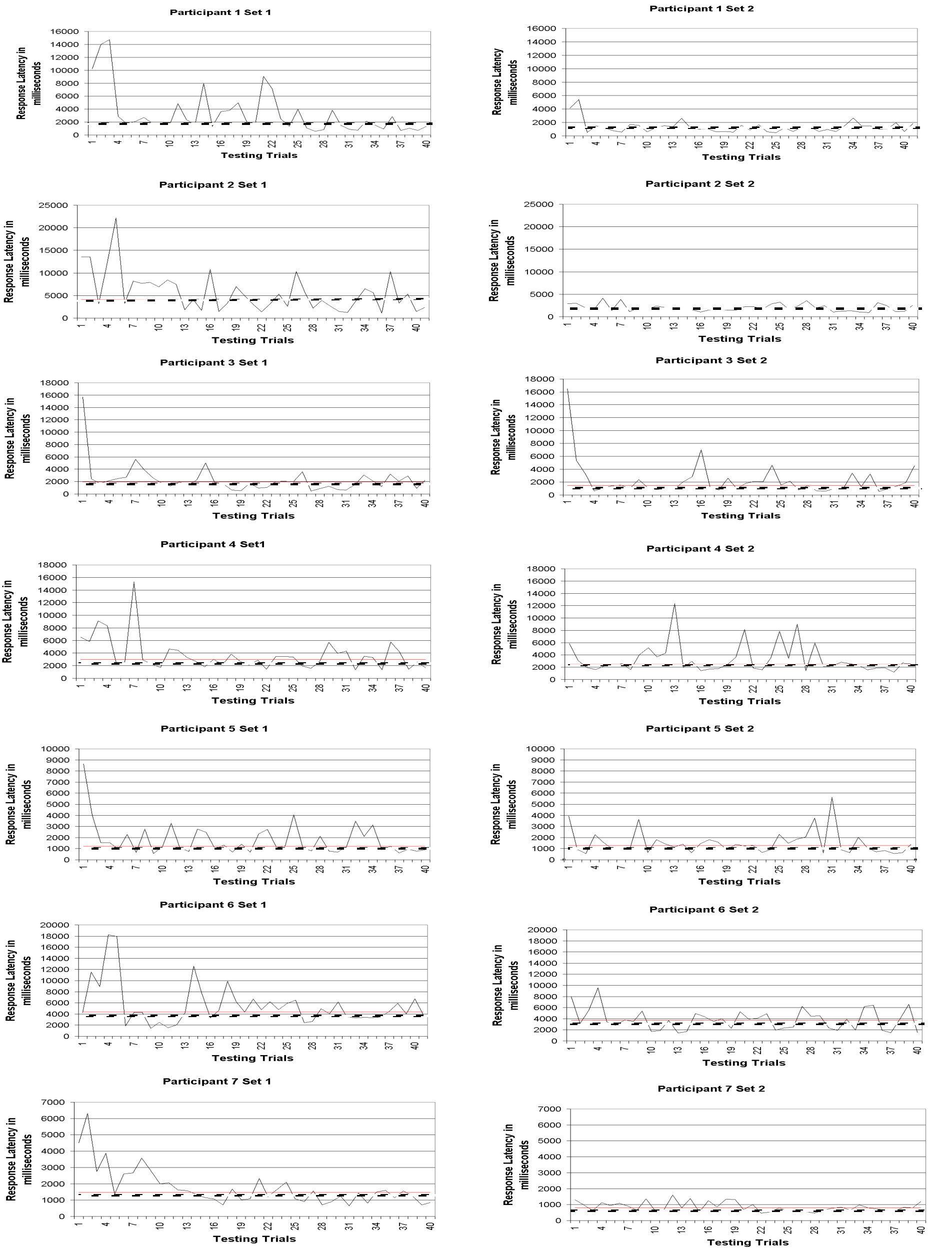

Figure 3. Each participant's reaction times to successive probes during the first successful exposure to the relational test using both the original (Set 1) and novel (Set 2) stimulus sets. Hashed horizontal lines represent the mean response latency for the entire test phase.

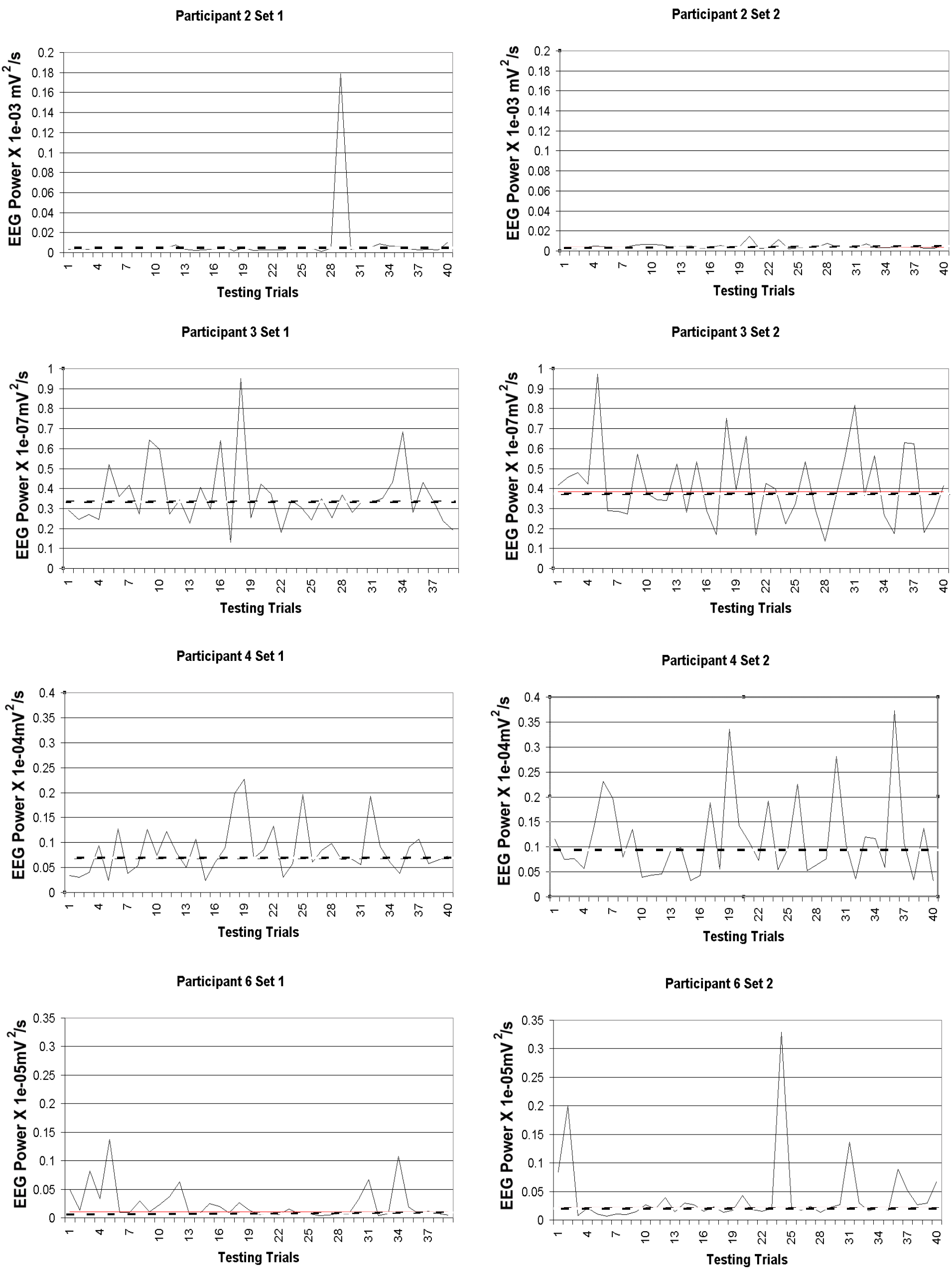

Figure 4. EEG responses in mV^2/s to each successive probe during participants' first successful exposure to the relational test using both the original (Set 1) and novel (Set 2) stimulus sets. Hashed horizontal lines represent the mean EEG power during the entire test phase.

set (M= 1775.675, SD= 1156.1559) and the novel stimuli set (M= 869.325, SD= 292.1251). The difference was significant (Wilks' Lambda= 0.601, F(1,39)= 25.85, p< 0.01, multivariate eta squared= 0.399).

Participant 3 demonstrated a mean decrease in response latency between the original stimuli set (M= 2354.675, SD= 2444.2241) and the novel stimuli set (M= 2290.875, SD= 2709.146). However, this difference was not significant (Wilks' Lambda= 0.999, F(1,39)= 0.055, p= 0.815, multivariate eta squared= 0.001). Participant 4 showed a mean decrease in response latency between the original stimuli set (M= 3688.125, SD= 2605.4392) and the novel stimuli set (M= 3331.8, SD= 2395.544). This difference was not significant (Wilks' Lambda= 0.99, F(1,39)= 0.385, p= 0.539, multivariate eta squared= 0.01). Finally, Participant 5 demonstrated a mean decrease in response latency between the original stimuli set (M= 1795.9, SD= 1492.6335) and the novel stimuli set (M= 1518.75, SD= 1069.0369), but this difference was not significant (Wilks' Lambda= 0.971, F(1,39)= 1.169, p= 0.286, multivariate eta squared= 0.029). In summary, all seven participants showed a decrease in mean response latencies from the original to the novel stimulus sets, and for four of these participants that effect was statistically significant.

For the purposes of EEG analysis a 50Hz notch filter and a low pass filter were applied to the raw data. Analysis focused on the alpha band (8-13 Hz) because it has commonly been cited as a measure of relaxation (see Fisch, 1999). Thus, a more mentally alert participant will show *less* alpha band activity at the electrode sites. Alpha band activity was quantified in terms of units of power per unit time (mV^2/s) within the alpha band.

The EEG data was divided into epochs that lasted from the presentation of a stimulus to the subsequent response, in accordance with the electrical event markers on the EEG record. The epochs were then further reduced so that only the middle 50% of each were used in the analysis. This was done to eliminate artifacts, such as blinking, that commonly occur in the outer 50% of a given epoch (Fisch, 1999).

The software Matlab [www.mathworks.com] was used to perform the digital signal processing required to analyze the raw EEG data. The raw data, sampled at 200Hz, was divided into segments corresponding to the middle 50% of each data epoch as described above. A notch filter implemented as a digital version of a bandstop Butterworth filter (fourth order, cuttoff frequencies 45Hz. and 55 Hz) was first applied to reduce the 50Hz contamination in the signal from the electrical supply. The alpha band was then extracted using a bandpass digital butterworth filter (fourth order, cutoff frequencies 8Hz and 13Hz.). Total EEG power per unit time was then calculated using this signal.

A large number of artifacts were observed for some participants, as is typically observed in EEG recordings. Specifically, data collected from Participants 1, 5, and 7 appeared to contain more artifacts than EEG data, so these participants' data was removed from the analysis.

Table 3 shows the mean alpha band power for the original and novel stimulus sets for each of the four remaining participants. For Participants 3, 4, and 6 there is increased alpha band activity (suggesting decreased higher-cognitive activity at the

Table 3. Median alpha band EEG power in millivolts per second (mV2/s) per trial during the first successful exposure to both the original (Set 1) and novel (Set 2) stimulus sets.

Participant	Set 1	Set 2
2	0.0043 x1e-03 mV2 /s	0.00385 x1e-03 mV2/s
3	0.3388 x1e-07 mV2/s	0.3848 x1e-07 mV2/s
4	0.0707 x1e-04 mV2/s	0.0962 x1e-04 mV2/s
6	0.0108 x1e-05 mV2/s	0.02205 x1e-05 mV2/s

electrode sites) from the original to the novel stimulus set. Figure 4 shows each participant's EEG responses in mV^2 per second (mV^2/s) to each successive probe during the first successful exposures to the relational test using both the original (Set 1) and novel (Set 2) stimulus sets.

Inferential statistical analysis would not be appropriate for the current data as it has already been transformed by an averaging technique in the creation of response epochs. Furthermore, as with all EEG data, it has been heavily filtered to remove movement artifacts and ambient electrical interference.

Discussion

In the current study response latencies were seen to systematically decrease, both across and within relational testing blocks, for all participants. Moreover, median response latencies decreased from the original to the novel stimulus sets for six of the seven participants and the decrease in response latency from the original to novel stimulus sets was significant in the case of four of the seven participants. Thus, while not all trends were statistically significant, the overall trend of the data overwhelmingly suggests a practice effect across trials and stimulus sets. The observed pattern of response latency decrease across stimulus sets strongly suggests that the relational skills assessed using stimulus Set 2 were established in an exemplar-like fashion with stimulus Set 1.

It must be noted that studies of derived relational responding using response latency as a measure logically encounter natural floor effects. Participants learn quickly and the decrease in response latency over trials becomes less dramatic as participants are hindered by the physical constraints of responding through button presses on a keyboard. In effect, data quickly asymptotes towards the minimum across trials. Thus, it may be argued that the decreases demonstrated for some participants both within and across stimulus sets are especially impressive, given the natural limitations to decreases in response latency.

The current study extends upon the earlier findings of Steele and Hayes (1991) and O'Hora et al. (2002) in that derived relational responding performances, measured through response latency, improved with practice and generalized to novel stimuli. While O'Hora et al. demonstrated this effect at the level of mutual entailment, the current study examined the effect at the level of combinatorial entailment. Moreover, while Steele and Hayes (1991) did analyze response latency at the level of combinatorial entailment, they did not examine practice effects in derived relational responding within and across stimulus sets.

The current study appears to support the RFT position that derived relational responding represents a generalized operant activity. According to RFT theorists, derived relational responding, as a form of operant behavior, should, among other things, develop over time and generalize to novel stimuli. The current study found both a development of derived relational responding over time and a generalization of the repertoire to a novel stimulus set. Response latencies decreased towards the minimum, both within and across relational testing sets, providing an index of increased proficiency across time.

The implications of the EEG data are more difficult to derive, given the sophistication of the measure. Electrical interference from ambient sources is a perennial problem in EEG research and noise produced by eye-blinking and other movement artifacts is impossible to avoid. Future research should consider the use of multiple simultaneous EEG records from several electrode placement sites so that an average EEG record can be obtained. In any case, the current data show a general trend towards greater alpha band power on the second stimulus set. Greater alpha band power implies more relaxation and less higher cognitive activity (Fisch, 1999). Thus, the current study would appear to support the RFT position that subjects' proficiency (measured here as mental effort) at derived relational responding should, like any operant activity, increase across trials and stimulus sets.

Conclusion

Overall the current findings describe the real-time acquisition of a derived relational responding repertoire in terms of response latency and EEG measures. The data show that both within and across stimulus sets subjects show increased proficiency with derived relational responding as predicted by the RFT account. This increased proficiency is apparent in the successive decreases in response latencies and corresponding decreases in higher cognitive brain function as measured by alpha band power. It is important to understand that these measures are not used here as explanatory mechanisms in any way, but rather as novel means of quantifying derived relational activity as an operant behavior. While no one study of this kind can establish definitively that derived relational responding is an operant activity, the current data, taken together, seem to point decidedly in that direction.

References

Barnes-Holmes, D. & Barnes-Holmes, Y. (2000). Explaining complex behaviour: Two perspectives on the concept of generalised operant classes. *The Psychological*

Record, 50, 251-265.

Barnes-Holmes, Y., Barnes-Holmes, D. Roche, B, & Smeets, P.M. (2001a). Exemplar training and a derived transformation of function in accordance with symmetry. *The Psychological Record, 51*, 287- 308.

Barnes-Holmes, Y., Barnes-Holmes, D. Roche, B, & Smeets, P. M. (2001b). Exemplar training and a derived transformation of function in accordance with symmetry II. *The Psychological Record, 51*, 589-603.

Barnes-Holmes, D., Hayes, S.C., Dymond, S., & O'Hora, D. (2001). Multiple stimulus relations and the transformation of stimulus functions. In S. C. Hayes, D. Barnes-Holmes, & B. Roche (Eds.), *Relational frame theory: A post-Skinnerian account of human language and cognition* (pp. 51-71). New York: Plenum.

Bentall, R.P., Dickins, D.W., & Fox, S.R.A. (1993). Naming and equivalence: Response latencies for emergent relations. *The Quarterly Journal of Experimental Psychology, 46B*, 187-214.

Cohen, J.D., MacWhinney, B., Flatt, M., & Provost, J. (1993). PsyScope: A new graphic interactive environment for designing psycology experiments. *Behavioural Research Methods, Instruments and Computers, 25*, 257-271.

Davidson, R.J., Jackson, D.C., & Larson, C.L. (2000). Human electroencephalography. In J.T. Cacioppo, L.G. Tassinary, G.G. Berntson (Eds.). *Handbook of Psychophysiology* (2nd Ed.). Cambridge University Press: New York.

Deutsch, C.K., Oross, S. III, DiFiore, A., & McIlvane, W.J. (2000). Measuring brain activity correlates of behaviour: A methodological overview. *Experimental Analysis of Human Behaviour Bulletin, 18*, 36-42.

Dickins, D.W., Singh, K.D., Roberts, N., Burns, P., Downes, J.J., Jimmieson, P., & Bentall, R.P. (2001). An fMRI study of stimulus equivalence. *NeuroReport, 12*, 2-7.

DiFiore, A., Dube, W.V., Oross, S.III, Wilkinson, K., Deutsch, C.K., & McIlvane, W.J. (2000). Studies of brain activity correlates of behaviour in individuals with and without developmental disabilities. *Experimental Analysis of Human Behaviour Bulletin, 18*, 33-35.

Dube, W.V., Green, G., & Serna, R.W. (1992). Auditory successive conditional discrimination and auditory stimulus equivalence classes. *Journal of the Experimental Analysis of Behaviour, 59*, 103-114.

Dymond, S. & Rehfeldt, R.A. (2001). Supplemental measures of derived stimulus relations. *Experimental Analysis of Human Behavior Bulletin, 19*, 8-12.

Elger, C.E., Grunwald, T., Lehnertz, K, Kutas, M., Helmstaedter, C., Brockhaus, A., Van Roost, D., & Heinze, H.J. (1997). Human temporal lobe potentials in verbal learning and memory processes. *Neuropsychologia, 35*, 657-667.

Fisch, B.J. (1999). *Fisch and Spehlmanns EEG primer: Basic principles of digital and analog EEG* (3rd ed.). Amsterdam: Elservier Science.

Hayes, L.J. (1992). Equivalence as process. In S.C. Hayes & L.J. Hayes (Eds.), *Understanding verbal relations* (pp. 97-108). Reno, NV: Context Press.

Hayes, S.C., Barnes-Holmes, D., & Roche, B. (2001). *Relational Frame Theory: A post-Skinnerian account of human language and cognition*. New York: Plenum

Press.
Hayes, S.C., Gifford, E.V., & Wilson, K. (1996). Stimulus classes and stimulus relations: Arbitrarily applicable relational responding as an operant. In T.R. Zentall & P.M. Smeets (Eds.). *Stimulus class formation in humans and animals* (pp. 279-299). North Holland: Elsevier Science
Healy, O., Barnes-Holmes, D., & Smeets, P.M. (2000). Derived relational responding as generalised operant behaviour. *Journal of the Experimental Analysis of Behaviour, 74*, 207-227.
Hayes, S.C. Fox, E., Gifford, E.V., Wilson, K.G., Barnes-Holmes, D., & Healy, O. (2001). Derived relational responding as learned behavior. In S.C. Hayes, D. Barnes-Holmes, & B. Roche (Eds.). *Relational Frame Theory: A Post-Skinnerian Account of Human Language and Cognition*. (pp. 21-50). New York: Plenum Press.
Hayes, S.C., & Wilson, K.G. (1996). Criticisms of relational frame theory: Implications for a behavior analytic account of derived stimulus relations. *The Psychological Record, 46*, 231-236.
Kennedy, C.H.(1991). Equivalence class formation influenced by the number of nodes separating stimuli. *Behavioural Processes, 24*, 219-245.
Lipkens, R., Hayes, S.C., & Hayes, L.J. (1993). Longitudinal study of the development of derived relations in an infant. *Journal of Experimental Child Psychology, 56*, 201-239.
O'Hora, D., Roche, B., Barnes-Holmes, D., & Smeets, P.M. (2002). Response latencies to multiple derived stimulus relations: Testing two predictions of relational frame theory. *The Psychological Record, 52*, 51-75.
Pilgrim, C., & Galizio, M. (1996). Stimulus equivalence: A class of correlations or a correlation of classes? In T.R. Zentall & P.M. Smeets (Eds.). *Stimulus class formation in humans and animals* (pp. 173-195). North Holland: Elsevier Science.
Pinel, J.P.J. (2000). *Biopsychology*. Boston: Allyn & Bacon.
Roche, B., & Dymond, S. (2003). Computer-interfacing for dummies: Interfacing peripheral devices to your Macintosh PC. *Experimental Analysis of Human Behavior Bulletin, 21*, 8-11
Roche, B., Stewart, I., & Barnes-Holmes, D. (1999). PsyScope: An easy-to-use graphical system for designing and controlling equivalence experiments. *Experimental Analysis of Human Behaviour Bulletin, 17*, 5-7.
Spencer, T.J., & Chase, P.N. (1996). Speed analysis of stimulus equivalence. *Journal of the Experimental Analysis of Behaviour, 65*, 643-659.
Steele, D., & Hayes, S.C. (1991). Stimulus equivalence and arbitrarily applicable relational responding. *Journal of the Experimental Analysis of Behaviour, 56*, 519-555.

Received December 5, 2003
Final acceptance February 15, 2004