REINFORCED BEHAVIORAL VARIABILITY IN HUMANS

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*This study aimed to assess the role of reinforced behavioral variability in the learning of a 6-digit target sequence (211212) with 3 groups of human participants (*n = 39*). For the first group (Control), only the target sequence was reinforced. For the second group (Any), the target sequence was reinforced, and any sequence other than the target sequence could be reinforced on a variable interval 60-s schedule. For the third group (Variable), the target sequence was reinforced, and any sequence other than the target sequence could be reinforced on a variable interval 60-s schedule, if it met a variability criterion. The Control group produced the target sequence significantly more often than the Variable group by the end of the experimental sessions. These findings contradict previous studies with rats that have shown that reinforcement of behavioral variability facilitates the learning of difficult response sequences but are consistent with results from previous studies with humans. Potential reasons for this disparity are discussed.*
Key words: operant conditioning, sequence learning, behavioral variability, reinforcement, humans

Early studies on operant learning have shown that exposure to schedules of reinforcement will generate characteristic patterns of responding, depending on the schedule in effect (Ferster & Skinner, 1957). It has been demonstrated that prolonged exposure to a schedule of reinforcement can lead to stereotypical response patterns (e.g., Antonitis, 1951; Schwartz, 1982). However, other researchers have shown that variability can be maintained when it is a direct requirement of the reinforcement contingency (Neuringer, 1986, 2002, 2004; Neuringer, Deiss, & Olson, 2000; Page & Neuringer, 1985). Reinforced variable responding has been shown to facilitate learning (Neuringer et al., 2000), to be resistant to extinction (e.g., Neuringer, Kornell, & Olufs, 2001), to generalize to new contexts (e.g., Harding, Wacker, Berg, Rick, & Lee, 2004; Pryor, Haag, & O'Reilly,

1969; P. D. Stokes, 2001; T. F. Stokes & Baer, 1977), and to be able to be maintained as long as it is functional (Neuringer, 2002). The ability to change behavioral variability is important to understanding creativity (e.g., Cherot, Jones, & Neuringer, 1996; Flora, 2004; P. D. Stokes, 2001) and skill acquisition (e.g., Harding et al., 2004; Pryor et al., 1969). It also has clinical applications, such as in cases where an individual's variability in behavior is typically low, as with individuals with autism (Miller & Neuringer, 2000) or depression (Hopkinson & Neuringer, 2003). Animal studies have shown that reinforcement of variability of response sequences can facilitate learning of difficult target sequences (e.g., Neuringer et al., 2000); however, research with humans has shown that reinforced variability interferes with the learning of difficult target sequences (e.g., Maes & van der Goot, 2006). It is this disparity that is the focus of the present investigation.

Neuringer et al. (2000) systematically studied the role behavioral variability may play in the learning of difficult sequences of left and right lever presses with rats, under three conditions of training. For the Control groups, reinforcement was awarded only for the emission of the target sequence, whereas for the Any groups, reinforcement was available for the target sequence and was also delivered on a variable interval (VI) 60-s schedule for any other sequence. The Variable groups could earn reinforcement for the target sequences and for any sequence that met a variability threshold on a VI 60 s (see Neuringer et al., 2000). The added reinforcement of the VI 60-s schedule increased the rate of responding for both the Variable and the Any groups, but only the Variable group, who received reinforcement for variability, showed evidence of learning the longer target sequences (Figure 1, left panel; Neuringer et al., 2000). These results led Neuringer et al. to conclude that reinforcing variability would promote more learning in rats than when reinforcement was not contingent on variability or when it was delivered only following production of the difficult target sequence.
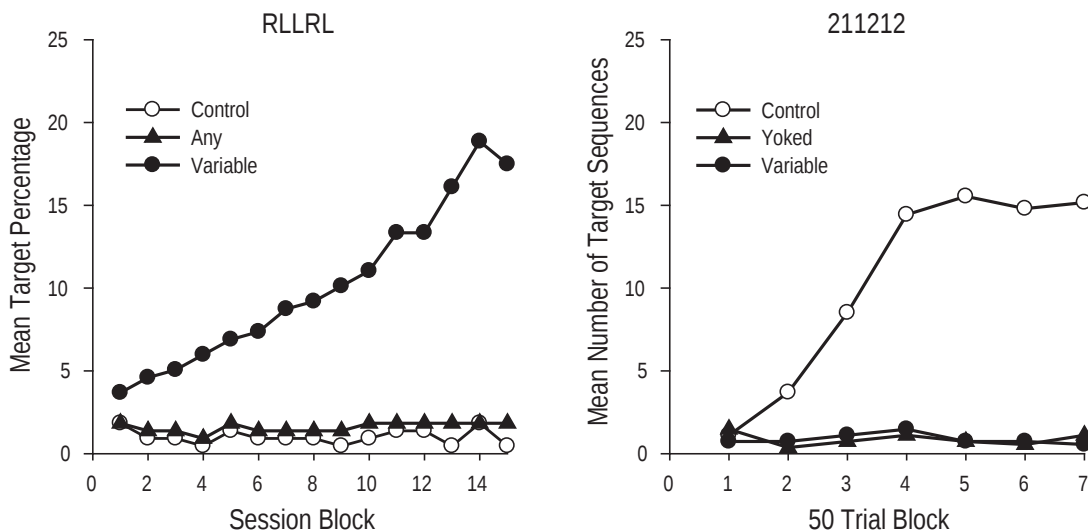

Figure 1. The left panel shows the percentage of trials in which the target sequence RLLRL was emitted. Adapted with permission from "Reinforced Variability and Operant Learning," by A. Neuringer, C. Deiss, and G. Olson, 2000, *Journal of Experimental Psychology: Animal Behavior Processes, 26*, p. 103. Copyright 2000 by the American Psychological Association. The right panel shows the mean number of target sequences across 50 trial blocks. Adapted with permission from "Human Operant Learning Under Concurrent Reinforcement of Response Variability," by J. H. R. Maes and M. van der Goot, 2006, *Learning and Motivation, 37*, p. 87. Copyright 2005 by Elsevier, Inc.

In an attempt to show the benefits of reinforced behavioral variability on learning in humans, Maes and van der Goot (2006) conducted a similar study with undergraduate students who responded on two computer keys. Their procedure was modeled on Neuringer et al. (2000), but there were some important differences. They chose a six-digit target

sequence consisting of the numbers 1 and 2 (211212), which was the sequence produced the least in a pilot study. By way of reinforcement, the word *correct* would appear on the computer screen for 0.5 s if participants produced a correct sequence. For the Control group, only target sequences were reinforced. For their Variable group, Maes and van der Goot employed a moving variability criterion, whereas Neuringer et al. kept their criterion constant. Additionally, Maes and van der Goot's equivalent of Neuringer et al.'s Any group used a yoking procedure that was not used in Neuringer et al.'s experiment with rats. The human participants in the Yoked condition had their sequence of reinforcer deliveries for non-target sequences yoked to participants in the Variable group, but as was the case for all three groups, they received reinforcement whenever the target sequence was produced. After a participant received reinforcement for producing a target sequence, he or she would not receive reinforcement for the next eight trials, regardless of whether sequences met the variability criteria or reinforcer delivery was arranged on the yoked schedule. If the participant produced the target sequence again, however, he or she would be reinforced.

Participants in the Control group were most likely to learn the target sequence, which did not support the prediction that reinforcing sequence variability facilitates the learning of difficult target sequences in humans (see Figure 1, right panel; Maes & van der Goot, 2006). It has been suggested that the contrasting results may reflect methodological differences between the two studies, such as the nature of the reinforcement (food vs. feedback), or the difference in the simultaneous schedules of reinforcement. Neuringer et al. (2000) used a VI 60-s schedule with a strict variability criterion, while Maes and van der Goot (2006) used a moving variability criterion where feedback on the secondary schedule was withheld for eight trials, if a target sequence had been produced. Another possible explanation is that the human participants were following self-generated hypotheses and therefore their behavior was not under the control of the reinforcement contingencies; rather, it was rule governed (Hayes, Brownstein, Zettle, Rosenfarb, & Korn, 1986; Lowe, Harzem, & Hughes, 1978; Skinner, 1976).

It does not help to resolve the different pattern of results reported by Maes and van der Goot (2006) and Neuringer et al. (2000) as being simply the product of a species difference. There have been a number of studies with humans that have used procedures analogous to those used with animals, which subsequently report similar patterns of behavior (e.g., Bizo, Remington, D'Souza, Heighway, & Baston, 2002; Galizio & Buskist, 1988). However, there is also a body of research that shows that human operant behavior appears insensitive to programmed reinforcement schedules (e.g., Joyce & Chase, 1990).

Another possibility for the disparity may have to do with how difficult the sequence is to learn. Elsewhere, sequence difficulty has been suggested to be a confound in learning experiments, and in incremental repeated acquisition experiments, sequences that require movement between alternatives have been shown to be more difficult to learn (Wright & Paule, 2007). The sequences used by Neuringer et al. (2000) and Maes and van der Goot (2006) do not appear to have been selected because they were demonstrated to be difficult to learn, though the sequences they used did require movement between alternatives, so these could be assumed to have been difficult. However, Maes and van der Goot did choose their sequence because it was one of the least produced sequences in a pilot study; it is this sequence that we use in the present study. One should be careful not to assume, however, that a low probability of production means a sequence is difficult.

The purpose of the current study was to examine some of the methodological issues raised by Maes and van der Goot (2006) and to explore other related procedures to test whether reinforcement of variability could promote sequence learning in human participants. In the present experiment, both the variability criterion and the added schedules of reinforcement were arranged to match more closely those used by Neuringer et al. (2000). To control for the possible confound of participants responding rapidly to escape the experimental session (see Lippman, 1994), participants were not told how many sequences were required, information that had been provided to their participants by Maes and van der Goot.

Method

Participants

The participants were 39 undergraduate students from Southern Cross University. They were randomly allocated to one of three groups: Control, Any, or Variable. The Control group consisted of 1 male and 12 females, with ages ranging from 19 to 48 years and a mean age of 27 years ($SD = 9.8$). The Any group consisted of six males and seven females, with ages ranging from 18 to 55 years and a mean age of 29 years ($SD = 12.4$). The Variable group consisted of five males and eight females, with ages ranging from 18 to 54 years and a mean age of 32 years ($SD = 13.7$). Participation in this study was voluntary, and participants signed informed consent forms prior to their participation.

Apparatus

The experiment was conducted in a testing cubicle in the learning laboratory at Southern Cross University. The room had no windows and contained an air conditioner that was set at 73° F. Participants sat at a desk with a PC computer with a 17-in flat screen monitor and standard QWERTY keyboard. A computer program written in Visual Basic 8.0 controlled and recorded experimental events. Participants used the "1" and "2" keys on the keyboard when entering their response sequences.

Procedure

The participants were tested individually and were asked to remove their watches and to turn off their mobile phones before the experimental session began. They then completed a short demographic questionnaire that asked for their age, sex, education level, and any previous knowledge of the experiment. Participants were then presented with a printed copy of the instructions that read,

> Your task is to enter a correct sequence of six keyboard keys. You are only allowed to use the keys numbered 1 and 2. You can enter any combination you wish providing you use these two keys. You will receive a point for each correct sequence and you will receive no points for an incorrect sequence. Your task is to earn as many points as possible by figuring out what a 'correct' and 'incorrect' sequence is. If you do not have any further questions, press 'Enter' to begin.

There was also a sign posted next to the computer monitor that read, "Your task is to earn as many points as possible by figuring out the correct sequence." The only instructions provided by the program was the message, "Please enter your sequence," which was displayed on the computer screen at the beginning of each trial and remained on the screen until the participant entered the last digit of the sequence. The participants could see each digit as they entered the sequence, and the digits remained on the screen for 2 s after the last digit in the sequence had been entered. Then feedback was provided. If the participant earned a point, the message, "You have scored a point" and the total number of points earned during the session were displayed on the screen for 2 s. If the participant did not earn a point, the message, "You have not earned a point" and the total number of points earned during the session were displayed on the screen for 2 s. To indicate the start of a new trial, the instructions, "Please enter your sequence" would return to the screen.

The target sequence of 211212 was the same target sequence used by Maes and van der Goot (2006). Sessions ended after 360 sequences had been entered or after 50 min had elapsed. Participants in the Control group could earn a point for entering the target sequence. Participants in the Any group were awarded points for entering the target sequence and, additionally, on a VI 60-s schedule for any sequence entered after the interval had elapsed. Participants in the Variable group were awarded a point every time

the target sequence was produced, as for the other two groups, and were also awarded points on a VI 60-s schedule for sequences other than the target sequence that met a variability criterion.

The variability criterion required that the relative frequency of a sequence was less than or equal to one over the total number of possible sequences minus the target sequence. For a six-item sequence of two digits, the total number of possible sequences, including the target sequence, is 64. The variability criterion was set at greater than or equal to 1/63, which represents maximum variability when there are 64 possible sequences including the target sequence. This criterion was taken from Neuringer et al. (2000), who defined a "variable" response as a sequence that had a relative frequency that was equal to or less than an even distribution of all possible sequences, not including the target sequence. Reinforcement for the target sequence reset the VI 60-s schedule for both the Any and Variable groups. The 2-s delay after entry of the sixth digit and the 2-s display of feedback were not included in the timing of the VI schedule.

Results

Participants in the Control group produced the target sequence more often than participants in the Variable or Any groups (see Figure 2). A Group × Trial Block repeated-measures analysis of variance (ANOVA) revealed a significant main effect for group, $F(2, 36) = 4.026$, $p = .026$, $\eta^2 = .183$, and Trial Block, $F(2, 80) = 16.7$, $p < .001$, $\eta^2 = .317$, with a significant interaction for Group × Trial Block, $F(4, 80) = 5.331$, $p < .001$, $\eta^2 = .229$. (Note: for all statistical analyses where assumptions of sphericity or homogeneity were violated, adjusted degrees of freedom were used; see Field, 2009.) Post hoc analyses conducted using Bonferroni adjusted alpha levels confirmed that the Control group produced significantly more target sequences than the Variable group ($p = .047$) in block 6. The difference between the number of target sequences produced by the Any group did not differ significantly from the Variable or Control groups ($ps > .05$).
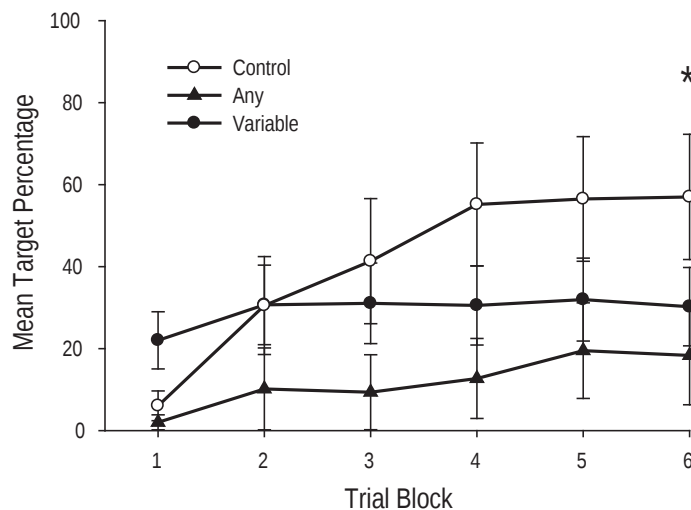

Figure 2. The mean percentage of target sequences (211212) emitted as a function of trial blocks. The error bars are the standard error of the mean. Trial blocks are the total number of trials in an experimental session divided by six. *$p < .05$.

The variability in sequences produced by the three groups also differed significantly. A Group × Trial Block repeated-measures ANOVA revealed a significant main effect for trial block, $F(3, 105) = 19.503$, $p < .001$, $\eta^2 = .351$; however, the main effect for group was not significant, $F(2, 36) = 2.268$, $p = .188$, $\eta^2 = .122$. The interaction effect for Group × Trial Block was significant, $F(6, 105) = 3.343$, $p = .005$, $\eta^2 = .157$. Figure 3 shows that as the experimental session progressed, there was a decrease in U value for each group. Post hoc analyses confirmed that the Variable group had a significantly higher U value than the

Control group in blocks 5 (p = .042) and 6 (p = .026). The U values for the Any group did not differ significantly from the Control or Variable groups (ps > .05).
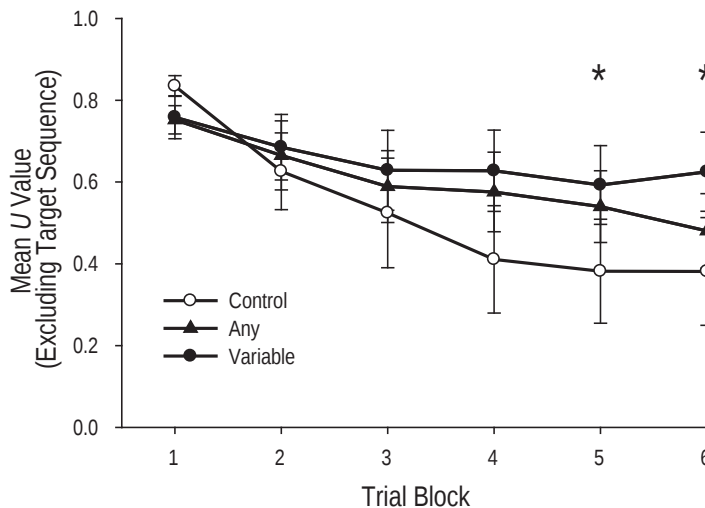

Figure 3. Mean U value excluding target sequence across trial block. The error bars are the standard error of the mean. Trial blocks are the total number of trials in an experimental session divided by six. *p < .05.

The mean number of reinforcers earned by each group differed significantly across groups as shown by a Group × Trial Block repeated-measures ANOVA, F(5, 32) = 4.836, p = .002, η^2 = .430; however, the trial block main effect was not significant, F(2, 36) = 2.204, p = .125, η^2 = .109. There was a significant interaction effect for Group × Trial Block, F(10, 64) = 2.600, p = .010, η^2 = .280. Figure 4 shows the mean number of positive feedback screens across trial block for each experimental group, with the Control group obtaining significantly more positive reinforcement than the Variable group for blocks 5 (p = .037) and 6 (p = .020). There was no significant difference in the mean number of reinforcers delivered to the Any and the Control or the Any and the Variable groups (ps > .05).

Figure 5 depicts the mean response rate for each experimental group across six equal trial blocks. A Group × Trial Block repeated-measures ANOVA showed a significant main effect for trial block, F(5, 32) = 5.036, p = .002, η^2 = .440; however, the main effect for group was not significant, F(2, 36) = .284, p = .754, η^2 = .016. The interaction effect between response rate and group was not significant, F(10, 64) = .655, p = .761, η^2 = .090. Post hoc analyses, with a Bonferroni adjusted alpha, showed that blocks 3–6 had significantly higher response rates than blocks 1 and 2 (ps < .05) and response rates were significantly higher in blocks 4–6 than in block 3 (ps < .05).

Discussion

The aim of this experiment was to determine if reinforcement of behavioral variability would facilitate the learning of a difficult target sequence in humans, as has been shown previously with rats (Neuringer et al., 2000), but not with humans (Maes & van der Goot, 2006). We matched our methodology more closely with that used by Neuringer et al. (2000) to test if methodological differences between the two previous studies might have accounted for the disparate results. The results of the current study support the findings of Maes and Van der Goot (2006); the Control group, who only received reinforcement for producing the target sequence, produced the target sequence significantly more often than the Any and Variable groups, who received reinforcement for entering sequences other than the target sequence.

While this study attempted to replicate the methodology of Neuringer et al. (2000) more strictly than Maes and van der Goot (2006), there are procedural differences between the studies still that may account for the difference in the findings. The most obvious
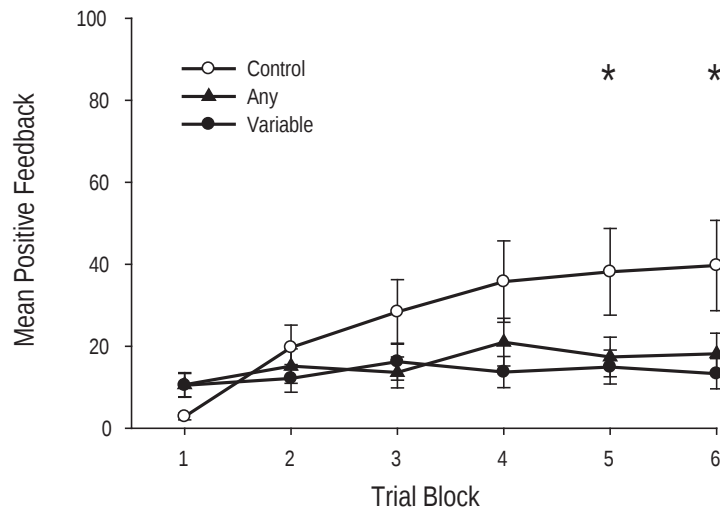
Figure 4. Mean number of positive reinforcements presented as a function of trial block. The error bars are the standard error of the mean. Trial blocks are the total number of trials in an experimental session divided by six. *p < .05.
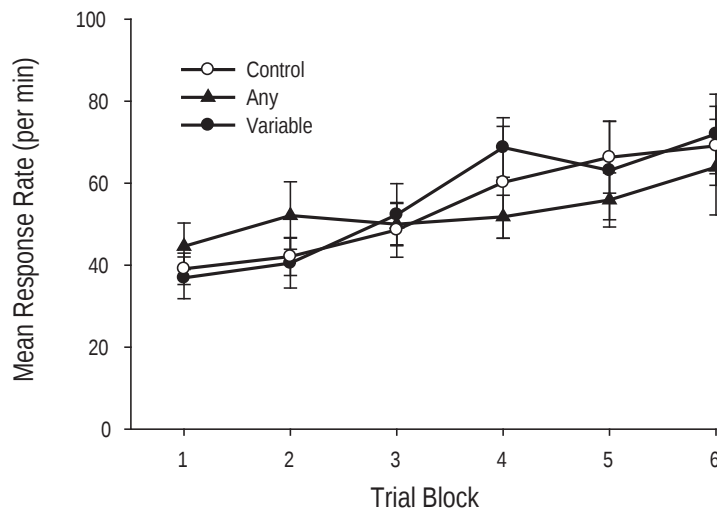

Figure 5. Mean response rate (per minutes) presented as a function of trial block. The error bars are the standard error of the mean. Trial blocks are the total number of trials in an experimental session divided by six.

difference is the species used in each study. This explanation was addressed by Neuringer (2009), who argued that this is probably not the cause of the disparate findings, as there have been many animal studies that successfully model human behavior. One key difference between studies with humans and non-human animals concerns the nature of the reinforcers used in those studies. Neuringer et al. reinforced the correct sequences produced by food-deprived rats with a primary reinforcer (food pellets), whereas human participants in the present study received "points," and participants in the Maes and van der Goot study received positive feedback by way of the word *correct* when they produced the correct sequence. The data from this study suggest that participants would respond for points, as the number awarded to participants increased significantly over the experimental session (as shown in Figure 4). It is unlikely that it is simply the difference in the nature of the reinforcement that accounts for the difference in findings between the human and animal studies.

The motivation to respond may be different between humans and animals on this type of task (Neuringer, 2009). The responding of the rats in the Control group of Neuringer et al.'s (2000) study extinguished, while participants in all three groups in this current study and that of Maes and van der Goot (2006) continued to respond throughout the experimental sessions. Neuringer (2009) suggested that the rats in the variability group of the Neuringer et al. study were motivated by the additional reinforcement they received from the VI schedule but that there may have been other aspects impacting the response patterns produced by humans. The verbal instructions given in this study and that of Maes and van der Goot (2006) to find a "correct" sequence may have interfered with the variability contingency (Maes & van der Goot, 2006; Neuringer, 2009). The participants' behavior may have become rule governed, rather than shaped by the reinforcement contingencies (Maes & van der Goot, 2006), such that the task of figuring out the correct sequence along with the added reinforcement of variability may have maintained the variable responding but distracted participants from learning the target sequence. Neuringer has suggested that removing the instructions and possibly offering a larger reward to the participant who earns the most points may attenuate the difference in findings between studies with animals and humans.

In the experiment by Neuringer et al. (2000), the rats experienced five experimental phases that differed in sequence length. The more difficult the sequence was, or more strictly speaking, the longer the sequence was, the clearer the difference in performance between groups. It may be that a six-digit sequence for humans is not difficult enough for the reinforcement of variability to facilitate more learning than direct reinforcement of the target sequence. Evidence for the notion of a difference in sequence difficulty between species can be found when you take a close look at the data reported by Neuringer et al. The rats in that study acquired the target sequences over many sessions, while the human participants in both the current study and Maes and van der Goot's (2006) study only participated in one 50-minute session. That the human participants could learn the target sequence in one session suggests that the target sequence may not be sufficiently difficult for the reinforcement of variability to show superiority over direct reinforcement of the target sequence.

Maes and van der Goot (2006) suggested that the target sequence chosen was sufficiently difficult, as only three participants came to emit the sequence frequently, and that a number of Control participants would not continue to produce the target sequence even though it was always followed by reinforcement. As the participants in Maes and van der Goot's study conducted the experiment in the home environment, it is possible that there were other factors impacting the production of the target sequence. The current study was conducted in the more controlled setting of a laboratory research cubicle, and 12 of the 39 participants produced the target sequence in 90% or more trials by trial block 6 (Control = 8, Any = 2, Variable = 2). It may be that for a task that is not sufficiently difficult for humans, the added reinforcement offered by the variability contingency served as a distraction, rather than aid, to learning. As already suggested, the verbal instructions given in both this study and by Maes and van der Goot may have influenced behavior more than the reinforcement schedules. Before any solid conclusions about the use of reinforced variability with humans can be made, the notion of difficulty of the target sequence needs to be explored further. Elsewhere, others have sought to study sequence-learning difficulty with non-human animals (e.g., Wright & Paule, 2007), and those methods may provide a means of quantifying sequence difficulty in future research.

Operant responding depends on context and consequence. When variation in some dimension of a response is not contingent, behavior can become stereotyped (e.g., Schwartz, 1982). When variability is a contingent requirement, then variability can be treated as an operant class in its own right (e.g., Neuringer, 2012; Page & Neuringer, 1985). Understanding how to increase variable behavior, when variability is a desired characteristic, is important, particularly in the fields of creativity (e.g., Cherot et al., 1996;

Flora, 2004; P. D. Stokes, 2001) and skill acquisition (Harding et al., 2004; Pryor et al., 1969) and in individuals typically low in variable behavior (e.g., Hopkinson & Neuringer, 2003; Miller & Neuringer, 2000).

The current study and those of Neuringer et al. (2000) and Maes and van der Goot (2006) do not operationalize the difficulty of the target sequence clearly. One would intuit that a sequence that involves alternations and varying lengths of repetition of the same response would be more difficult to learn than a sequence that involves infrequent alternations and long repetitive runs of the same response. Future research needs to pay more attention to the difficulty of the target sequence if there is to be further comparison between the animal and the human findings. Research is under way in our laboratory to explore the effect that sequence difficulty has on human sequence learning; will reinforcing variable responding promote the learning of a novel sequence by humans if the sequence is difficult enough?

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