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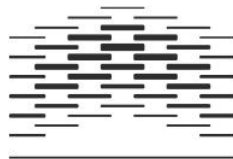# Learning in complex systems
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Variability

Rasmi Krippendorf

Faculty of Health Sciences
Department of Behavioral Science

OSLO AND AKERSHUS
UNIVERSITY COLLEGE
OF APPLIED SCIENCES

Contact:

Rasmi Krippendorf

Hagasvingen 14, leil. 312

1474 Nordbyhagen, Norge

mail@rasmi.no

Phone: (+47) 45 24 33 70

Contents

Theoretical Part

Research, theories and disputes

Contents

Experimental Part

Do lag schedules depending on responses or response classes yield different results,

and do genetic differences between SHR and WKY rats affect variability?

Tables and figures

Theoretical part

Research, theories and disputes

Abstract

The experimental studies of the behavioral phenomenon of variability and the connected metaconcept of creativity, have developed from being mainly descriptive, to becoming more predictive and in control of the dependent variables in scientific experiments, particularly in laboratories using operant chambers. After experiments with shaping new behavior in a publicly displayed porpoise, Karen Pryor and colleagues suggested that creativity and variability could be reinforced directly. Other researchers have followed up on this claim in the laboratory, with gradually more detailed and precise findings, studying different species under different contingencies and schedules of reinforcement, and elaborating over several related issues like the correlation between changeover and variability. Among the dedicated researchers, notably, is Allen Neuringer, who have orchestrated numerous experiments and written an impressive amount of articles on the matter. The history of his and other researchers' studies on variability, both comparative and with human subjects, are outlined; and the theories and explanations based upon the findings are presented and discussed. On the theoretical side, a major point is Neuringer suggesting that variability be labelled an operant in its own right. The dispute over this, with referral to what constitutes an operant according to B. F. Skinner and Charles Catania, and whether variability is explained better by already existing basic principles of behavior analysis, is addressed. Other minor discussions concerning incongruences in experimental results are also treated, among them the basis for the present study in the experimental part of this thesis. This concerns whether different practices in the use of lag schedules can explain different findings in experiments on variability, with otherwise similar subjects under similar contingencies of reinforcement. Finally, some conceptual problems are addressed, and future research along a return to the connection between variability and creativity is suggested.

Keywords: variability, creativity, operant class

Variability

Variability can be considered a piece of the puzzle of *creativity*. How does novel behavior come about, and why do some individuals of a given species show more or less novel behavior than others under the same contingencies? Removing this thesis from the subject of artistic or culturally dependent verbal behavior in any form, and restricting creativity to mean only the display of novel behavior (in any species), speculations in biologically and genetically selected traits of importance to survial naturally offer themselves as explanations as to why organisms sometimes display completely unexpected responses to stimuli; but what is controlling these responses in the specific situation? Why are the same stimuli suddenly eliciting novel behavior in an organism when the moment before it did not?

Creativity as a human faculty, as some kind of inner agent of divinity or power to create, is not a valid scientific viewpoint and must be discarded right away for further studies to prevail in getting at a more true explanation. It is possibly in realization of this, that the research has focused on the less mentalistically connotated term of variability. In early studies the broader view of creativity allowed for new behavior in settings with little or no restrictions as to what behavior was elicited and observed; today, only a set of specific behaviors are recorded. While the narrowing of focus has benefitted our understanding of some basic principles, it also have changed the fundamental area of research in such a manner that it is no longer creativity as such, in the form of novel behavior, that is being studied, but rather the effects of delayed reinforcement upon the frequency and changeover between already well known elicited responses.

The justification of this would be that variability, as stated in the opening sentence, is a part of creativity, and shedding light on this part is shedding light on an important aspect of creativity. In the public eye, however, variability is of little concern, whereas creativity is a larger issue; directing the research back toward a larger perspective and publishing behavior analytic, empirically evidenced explanations for creativity would possibly benefit the science of behavior as a whole. For the present thesis, this is treated at the end of the theoretical part, after a survey of the research.

Some researchers claim that the present findings warrant labeling variability as an operant. What constitutes an operant and the theoretical basis for suggesting this is treated later in this thesis, as well as the debate that has followed the notion. While many studies point to the possibility of reinforcing variability directly, in a manner similar to other aspects of behavior, like frequency, force, topography and so on, researchers have also found that when reinforcing other such conceptual relations (like switching) similar results turn up. This calls for caution in proclaiming variability the actual source of what takes place, and would be an argument against accepting it as an operant. Also, on a sceptic note, other researchers and scholars have analyzed sets of data in different ways, and claim that the results are already explained by existing principles of the science of behavior, viz as a result of the interchange between intermittent reinforcement and extinction; and that there is no need to consider variability an operant. The different viewpoints on this subject are presented and elaborated, and followed by an outline of various other minor disputes among the scientist that have worked with variability.

One of these disputes has been concerned with the differences found when reinforcing a specific response on a lag schedule versus reinforcing a class of responses on the same lag schedule. While some research have used one method, others have used the other, and differences could well be attributed to this minor difference in how a lag schedule is restricted. Also the number of actual operanda in use is of interest in a comparison between studies. The empiric part of this thesis is based on this incongruence and tries to display if there is indeed a difference between the two different applications (the thesis also investigates a genetically selected difference in their reactions to variability in two strains of rats).

For the benefit of the reader a short list of definitions of terms and measurements used in this thesis is provided on the next pages.

Definitions

Creativity is defined here as any new behavior not previously performed by an organism. It is a hypothetical construct that covers multitudes of behaviors and should thus be operationalized in

each instance. A major point is whether the behavior can be seen and agreed upon by multiple independent observers. Another point is whether the term should be reserved for only those responses that fall outside a naturally occurring or species specific behavior. The term is predominantly used in the early literature of the researchfield, as a near synonym of variability, but has since been replaced by this, since research and theory for practical reasons have focused mainly on how to create and maintain repetition of two or more behaviors intermixing relatively at random.

Lag n is a schedule in which *n* specifies the number of other responses required before the present response will yield reinforcement. There are different practices concerning this. The demands differ as to whether or not the other responses must be on various operanda or can be on same.

Operandum (plural: *operanda*), any device or mechanical construction that allows an organism to respond in a predetermined way. This is used for precise recording of responses, as when a lever is pressed and activates a microswitch. The lever is the operandum.

Previous (followed by number) is a measure of whether the present response is following a set number of previous differing responses. Some researchers have used criteria that only ask for previous responses to be different from the present response; others have added the extra demand that the previous responses also be different from each other. Previous *x* is counted in whole numbers per occasion and is a measurement of variability.

Repetition is a stereotypic response repeated on only one operandum. It is counted in whole numbers per occasion and is a negative measurement of variability.

Stochastic is a technical term, synonymous with random.

Switching (also called *changeover*) is the number of times the organism has responded between two operanda. The first switch occurs at the third response back on the first operandum (A, B, A) and switching then continues on every renewal (A, B, A, B, A will count as 3 switches). Switching is a measure of stereotypy and variability, when two or more operanda are available and is counted in whole numbers per occasion.

Variability is defined here as behavior that is not repetitive within certain criteria. These criteria have been different from experiment to experiment, for instance by registering the sequence of a set number of responses and only reinforcing the response that is not repeating this sequence. Another way has been to allow for repetition on one operandum for as many times as required for another operandum to deliver reinforcement. To require the sequence of responses to be on different operanda has also been done in experiments. However, variability does refer to behavior that is repetitive when seen outside the specific criteria and is thus not the same as creativity. Variability can be given as the value *U* in percentages, as a number between 0 and -1, where 0 indicates absolute repetition and -1 signifies continuous variability according to the set criteria (but in connection to a dispute concerning whether variability should be considered an operant, objections to using this measure as a general denominator of variability have been raised by Lourenço de Souza Barba, 2012).

Research

Karen Pryor, Richard Haag and Joseph O'Reilly (1969) published an article on the supposedly creative abilities of a porpoise, claiming that creativity itself could be reinforced. As trainers at the Sea Life Park in Hawaii they had observed an animal, Malia, being responsive to reinforcement of previously unconditioned behavior when doing five daily shows at the Ocean Science Theater, and wanted to try this out with another porpoise under more strict control and in a less public manner.

A «docile, timid» porpoise named Hou was chosen for the experiment and methodological procedures for observation, registration, intervention and reinforcement were constructed. Any movement not part of the normal swimming action of the animal was reinforced by the trainer and recorded by two independent observers. Sometimes recurring movements were also chosen for reinforcement. Sessions were taped on video which was then used to calculate interobserver reliability. Two to four training sessions were run daily, lasting from 5 to 20 minutes, and after 32 sessions, the responses of the animal became too complex for the observers to describe and

discriminate, so the experiment was terminated. A diagram of specific novel behaviors were drawn

and distributed among 12 people that had firsthand knowledge of training with porpoises, asking

them to rank the sketches in order of frequency of occurrence in a free-swimming untrained animal:

This to ensure that the novel responses were in fact novel and outside the normal behavioral

repertoire of a porpoise.

What the experimenters found was that they had established 16 new behaviors in Hou, many

of them never to have been seen to occur spontaneously in the species. The authors concluded that

by «using the technique of training of novelty it should be possible to induce a tendency towards

spontaneity and creative or unorthodox responses in most individuals of a broad range of species.»

While the study of creativity is a valuable scientific endeavour in its own right, following

the original publication of Pryor and her colleagues, a less broad field of research has centered

around the concept of *variability*. Where the porpoises responses were recorded and reinforced in a

free-flowing manner, allowing for spontaneous novel behaviors to occur and be observed, the study

of variability is rather more restricted. It is often the same topographically identical responses that

are recorded, but over a variety of operanda. In this line of experimental research some have found

that variability as a higher order class of behavior could not be established through reinforcement

per se (notably Schwartz, 1982) while others have come to the opposite conclusion. Suzanne Page

and Allen Neuringer (1985) arranged multiple experiments with pigeons being reinforced for

pecking eight times on left and right response keys if in the present trial the pattern of these pecks

differed from the patterns in the last *n* trials. In one of the experiments *n* was set as high as 50

sequences and the pigeons generated highly variable patterns. Another experiment gradually

increased the required number of responses per trial, also generating a high level of variation in

sequences, maximizing at Lag 25 schedules. To illustrate the importance of the reinforcement to be

contingent upon the variability itself, Page and Neuringer conducted a yoked experiment where the

behavior of four pigeons was first reinforced on a Lag 50 schedule and then later given the same

amount of reinforcers on a variable ratio schedule, but with no demand to peck in variable

sequences. Page and Neuringer also found that they could convincingly establish stimulus control and make pigeons peck in variable patterns under red lights and in repetitive patterns under blue light. From this thoroughly conducted series of experiments, Page and Neuringer concluded that variability could be considered an operant dimension of behavior, on the same level as frequency, force, duration, location, and topography.

Continuing this line of research, Neuringer (1993) arranged another series of experiments, this time with both pigeons and rats, and found several interesting points. First, when establishing a baseline of variability between the last five sequences (a Lag 5 schedule) of four left and right lever presses, for example LLRR, it was possible to strengthen or weaken particular sequences by always reinforcing or not reinforcing them. Secondly, from a perspective of topography or economy of movement, an easy versus a difficult set of sequences were aligned and Neuringers experiments showed that the level of difficulty influenced the selectively strengthening effects when a particular sequence was always reinforced. Thus, the same reinforcer can establish variability and at the same time strengthen particular instances of behavior, depending on the topography or difficulty of the behavior.

For a field of study to be of more than interest to a few scholars, it needs to be of social, economic, political or otherwise importance. Variability, being a part of creativity is naturally interesting in its own right, but it also has practical value. Especially in the treatment of different human disorders, researchers have found certain things that are directly applicable outside the laboratory. One such functional study by Hunziker, Saldana and Neuringer (1996), using two strains of rats, found that rearing environment did not influence response variability, but had an impact on body weight and response rate. Also, the strain called *spontaneously hypertensive rat* (SHR), when compared to the strain *Wistar-Kyoto* (WKY), showed a higher level of responses overall and a general higher level of variability, whereas the other strain showed to be more sensitive to the contingencies of variability (or lack of them). This can serve as a model for children with the diagnose of *attention-deficit/hyperactivity disorder,* ADHD, when compared to normally developing

children (Terje Sagvolden, 2000). The study suggests that in the further study and treatment of ADHD, focus should be directed to other areas than whether or not children grow up in enriched or impoverished environments. The experimental part of the present thesis is following up on this study, examining differences in response rates in the same two strains of rats during sessions under two slightly differing ways of administering lag schedules.

Armando Machado (1997) did a similar series of studies with pigeons, in effect replicating some of the findings of Neuringer, but with a focus on the rate of changeovers between different operanda. Like Neuringer, Machado used only two operanda, requiring similar topography of behavior, thus measuring variability in the switching between operanda. In the initial experiments, only a certain number of changeovers were required per sequence of eight pecks on two keys. In the main and final experiment, pecking was only reinforced when occurring in a sequence of eight pecks that had not occurred in the last 25 trials. Since Neuringer had gradually increased the number of how many trials were required to be different from the present, whereas Machado went straight to a Lag 25 schedule, the findings differed in number of received reinforcers (Machados pigeons did not get as many reinforcers paid out as did Neuringer's). The study pointed to several key issues in variability: First, when reinforcement is contingent not on variability per se, but rather on the switching between two keys, pigeons automatically vary the sequences of pecks. Second, it may be that reinforcing variability directly instead of reinforcing changeover is slightly more effective in generating variable responses. And third, Machado found that the location of the initial peck in sequences functioned as an organizing element – thus introducing a level of supposed randomness or stochasticity in the last few pecks of each sequence.

Creativity is a large field of scientific interest, with many branches of applicability into for instance the treatment of stereotypy in patients with autism. Studying variability can be seen as a steppingstone to gain more insight into the underpinning workings of creativity, and also into the functional elements of learning. Some of the links between creativity, learning and variability were experimentally examined in two experiments by Allen Neuringer, Chris Deiss and Gene Olson

(2000), who let the behavior of three groups of rats be reinforced in different phases for particular target sequences of left and right lever presses, divided into easy and difficult sequences. Besides receiving reinforcers contingent upon the target responses, variable sequences of responses in one group (VAR) were reinforced concurrently once per minute, while another group received reinforcers for any response (ANY), independent of whether or not they varied. The last group functioned as control (CON), receiving reinforcers only contingent upon target sequences. The experiment ran over several phases, changing what target sequence or sequences were required for each group and ending every phase with remedial specific shaping of the behavior of those subjects that had too low frequency of response on a particular sequence, ensuring that every new phase was started by equally well performing subjects.

In the first experiment, subjects were to learn five different sequences of easy to medium difficulty, while the second experiment required new subjects to learn one sequence of hard difficulty. The easy sequences were learned equally rapidly and well by all groups, whereas the more difficult sequences was learned only by the VAR group. The CON group had an overall lower response rate than did the animals from the other two groups in the cases of difficult sequences; although the ANY group held a high number of responses, the rats in this group did not learn the difficult sequences either. Since other factors were held relatively constant, it was prudent to conclude that the contingencies of reinforcement for variability accounted for the differences in learning.

The implications of this study are primarily to enlighten our understanding of how shaping can take place when response variations are being generated and modified. When particular responses are being discriminatively reinforced in combination with concurrent reinforcement for varied behavior, the result could be a faster and better learning of specified behaviors, and this should have an impact on our theories on learning. But the study also shows another important point: The detrimental effect of reinforcing behavior non-contingently can possibly be avoided. Non-contingent reinforcement, although often successful to alter behavior, can trigger problem

behavior in connection with its eventual fading or extinction, that is, because the reinforcement is not contingent upon a specific behavior, the risk of reinforcing something unwanted is present and later withholding of reinforcement can evoke extinction bursts. To implement a reinforcement program for response variation could help minimize or avoid these effects.

Within the field of behavior analysis, extinction has a twofold meaning, as a process and as a procedure. As a process, it is a description of what happens to the behavior of an organism, when it no longer receives reinforcement for a previously reinforced behavior. As a procedure, it is the withholding of reinforcers. It has been well established that extinction usually leads to a decline in the frequency of target behavior over time, but the organism is often first displaying what is referred to as extinction burst – the organism elicits more responses and with great variation. So what happens during extinction when the reinforced behavior class is variation itself? Allen Neuringer, Nate Kornell and Matt Olufs (2001) tried to shed light on the matter by setting up three experiments with fifty rats. The first was simply to run extinction after having established variability between three operanda (two of these required a similar topography of response; the operanda were placed at different distances to the food-dispenser, thus allowing for a gradation of difficulty of the sequences). Withholding reinforcement slowed responding, but increased likelihood of variability. The different possible sequences of responses were distributed equally along both phases; the study documented that the least likely response sequences increased in frequency during extinction but maintained response structures (speed of response and probability of response depending on difficulty). The second experiment let half the rats from the first experiment return to reinforcement phase, while the other half were yoked to the first, independent of their own behavior. Reinforcement and extinction phases were repeated twice, thus replicating and enlarging the first experiment. Variability increased in both groups during extinction, and structure of responses were maintained. Finally, in the third experiment, a new batch of fifty rats were divided into two groups after initial shaping to respond on the three operanda. In one group only one sequence containing all three different responses was reinforced (established through backward chaining in the first trials),

while in the other group, random sequences of responses selected by a computer were reinforced. Both groups were then put on extinction, after an alignment phase for the first group to ensure that the specific sequence was thoroughly learned. The findings were consistent with the other two experiments: The least probable sequence of responses increased the most during extinction, suggesting a tendency to respond differently and away from the area of previous reinforcement. Extinction can be said to increase responding to operanda outside the originally reinforced. The study concludes that variability increases when reinforcement is withdrawn, but that what has been learned during reinforcement will be retained.

Moving from animal to human studies, Christopher Ross and Allen Neuringer (2002) conducted two experiments with a total of 81 subjects. The basic response in both experiments was to draw rectangles upon a computer screen with a mouse. In the first study, after an initial verbal instruction that outlined the study as a game with the objective to gain as many points as possible, one group of 20 participants were rewarded with a sound when varying the rectangles along three dimensions: shape, location and size (area); the sound supposedly functioning as a reinforcer of this behavior. Another group of 20 participants were yoked to the first to assure similar reinforcement frequency. The difference in variability contingencies met for the participants in the two groups were compared and results showed that the first group varied their drawing along all three criteria near three times as much as the yoked group, although still only on an average of approximately 20% of the time, but inclining over sessions. In the second experiment, one of the three criteria was reversed for each of three groups of participants, so that to comply for reinforcement, the rectangles had to vary on for instance shape and location, but be repetitive on size. For all three groups the required contingencies were met, id est, variability along two dimensions while repetition along one dimension were achieved, effectively showing that it is possible to obtain completely opposite effects from the same reinforcer, specifically variability and repetition, measured over differences in the particular individual's performance. This is relevant to specific problems with for instance the treatment of functionally maintained problem behavior.

In another study with human subjects, Ronald Lee, Jennifer J. McComas and Jennifer Jawor (2002) demonstrated that variability in the form of more varied verbal behavior could be established in two children diagnosed with autism. Failure to obtain similar result with a grownup participant, also diagnosed with autism, could be ascribed to differences in the methods implemented. After a baseline with differential reinforcement of appropriate verbal behavior, the researchers used a lag 1 requirement on verbal responses. All appropriate responses that differed from the immediately preceding response were reinforced. A reversal to baseline and again to implementation, showed control over the dependent variable for the two children. However, the reversal also shows that in spite of establishing variability in the setting, problems with generalization emerged.

Variability and *choice* were the subjects of a study by Matthew E. Andrzejewski, Claudia D. Cardinal, Douglas P Field, Barbara A. Flannery, Michael Johnson, Kathleen Bailey and Philip N. Hineline (2005). In a series of three experiments, pigeons were given access to reinforcement via choices that would lead to either schedules with high payout on different fixed-interval schedules or to random-interval schedules with little payout. The surprising finding was that pigeons not only actually chose the random-interval schedule; they did so more often than chance would predict, not favoring the fixed-interval schedule. Speculations in inner faculties such as of pigeons «prefering free choice» or similar, are not pertinent, but an explanation stems from foraging theory, where a systematic variability in procuring food may ensure the survival of a species and become part of the genetic makeup. Another two experiments with pigeons, conducted by Josele Abreu-Rodrigues, Kennon A. Lattal, Cristiano V. dos Santos and Ricardo A. Matos (2005) found a similar preference, not for the varied, but for the repetitive behavior, when concurrent-chains schedules with increasing lag-requirements were implemented. In effect, this research showed that there probably is a genetically struck balance between repetitive and variable responding to environmental stimuli in any given species. Thus, arranging contingencies of variability that promote creative behavior is possible, but will be limited if the task of generating new behavior becomes too costly. If there are alternative ways to procure reinforcement that do not require variability, those may be chosen

instead. Such a statement has practical relevance to for instance science itself, where the contingencies of variability could be arranged for new research (creativity), as opposed to the, although also important, repetitive behavior in the form of replications done.

Theories and disputes

As a subject matter for study, creativity is naturally of high interest in the field of behavior analysis. In the public opinion, however, it is often given as an opposite to the findings of the science, being attributed to willpower, self and other inner hypothetical constructs. To pinpoint the workings of creativity, defining what it means and how it comes about will possibly go a long way to make the science of behavior more palpable to a wider public. But there are too many views upon the subject; it is too broadly defined, being basically nothing more than a conceptual verbal construction; and maybe it is too personally related to us all, making us biased in either we believe in it as an inner agent for a unique autonomous self, or not.

Variability, on the other hand, does not hold the same connotations. It can be defined and limited within specific frames; operationalization is possible as the term can be applied directly to observable behavior as a description of relations between two or more different responses. It is no wonder therefore, that since the first reports about creativity (Pryor et al, 1969), the scientific focus has been directed to investigate variability. It can be postulated that an eventual return to the study of creativity will yield new exiting results as a consequence of the present interest in variability.

The experimental studies aside, a first important point to consider is the nature and status of the relations between two or more different responses. The definitions and concepts used in the science of behavior for such relations as exist between stimuli and response, or between response and consequence have been discussed and refined since the birth of the science and are called *operants*. Skinner (1935) wrote about the relation between stimulus and response, now named respondent or classical conditioning, using the terms introduced by Ivan Pavlov (1927); later the word operant conditioning became prominent as a term for the other part or for the broader three-term-contingency where the stimuli preceding and following a response, and the response itself, are

all part (Skinner, 1953). «...a set of contingencies defines an operant.» (Skinner, 1969, p. 131).

Charles Catania (1973) summarizes the history of the operant and points to a minor incongruence: An operant should rather be defined as the *orderly changes* in correlations along some specific dimension and not as a static relation between response and consequence. Such changes can show negative correlations as well, and Catania opens up for the possibility of including both such relations and other extensions, like «in terms of the times at which the responses occur or the stimuli in the presence of which they occur» (p. 112), as part of the operant relation. Catania never the less advocates a more specific use of the terms *class* and *relation* in connection with *operant*: «When an operant relation has been demonstrated, it is appropriate to say that contingencies have generated an operant class.» (p. 114).

Through experimental practice, it has become more and more evident that the relations between the three stimuli (precedent stimuli, response and consequence) are limited to a few numbers, and that only a few characteristics of them apply and suffice to explain the multitudes of behaviors constantly taking place. Thus, *reinforcement* is established as a basic process and an operant procedure; *punishment*, although still generating debate, is also considered a basic process, as well as the closely connected withholding of reinforcement, labelled *extinction*. Manipulation with basic aspects of a given behavior, like its occurrence, frequency, force, topography or mode of delivery, has empirically shown to be a reliable measure of operant relations and after a series of experiments suggesting that variability could indeed be reinforced directly, Page and Neuringer (1985) advocated to include variability as a dimension of behavior, and consider it an operant class. The theoretical implications were that an internal variability *generator* was activated through reinforcement of novel response sequences.

Though this suggestion is coming from the foremost researcher in the field of variability, it has raised some major considerations. First, Machado (1997) indicated that the supposedly independent nature of variability could be attributed to a more basic specific behavior, viz the switching or changeover frequency between operanda. By focusing on this directly observable

behavior, as opposed to more or less operationalized higher concepts or hypothetical constructs, his experimental findings point to a more mechanistic explanation of variability and puts more weight upon the dimensions of the responses involved than on a possible operant class as defined by Catania and suggested for variability by Page and Neuringer. Machado outlines the dimensions as distributions of force, duration, latency, location and topography across the members of a class of responses as typically becoming *less* variable when reinforced. It is in the reinforcing of particular changeovers between dimensions that he found a level of variability, or rather of stochastic responding. Nonetheless, Machado concludes his article with a comparison of his findings with those of Page and Neuringers, and states that «reinforcing sequence variability explicitly is slightly more effective at generating response variation than is reinforcing switching only» (p. 24). Perhaps in an attempt to align his more direct approach to the theoretical, yet so far unsustained claim of variability being an operant class in its own right, Machado seems to refute his opening statement, that «response variability may have been a derivative of more fundamental processes» (p.2).

In reply to Page and Neuringers suggestion, a second objection was raised by Lourenço de Souza Barba (2012) in a special issue of *The Behavior Analyst* that summed up the field. The measure of variability used by Neuringer and others have been a general value of *U*, and Barba points out that this has often been implemented independently of the sequence properties that provide contact with reinforcement. Variability could and should be deconstructed to more basic components, differentiation and discrimination. Armando Machado and François Tonneau (2012), in the same special issue, go even further and claim that also these components should be deconstructed to the more basic, primitive processes of reinforcement, extinction and generalization. A third, similar critique was raised by Per Holth (2012a): Although the experimental uncovering of variability is both relevant and important, Neuringer's «notion of variability as an operant on its own seems superfluous» (p. 248). The immediate effect of reinforcing a novel response is an increase in the frequency of this response, not a general increase in other novel or variable responses. The results unveiled in the research can be accounted for by already established

basic principles, and Holth maintains that the experiments so far have not shown any phenomenon that cannot be readily explained within the framework of intermittent reinforcement and extinction in continuous exchange. Skinner (1936) investigated the relation between conditioning, extinction and level of response (at the time called «drive») and found that the frequency of responses increase and the topography of the responses change during extinction, before a gradual decrease toward zero. This is now regarded a basic empirically evidenced phenomenon, called *extinction burst*. An interesting photo session with rats changing between continuous reinforcement and extinction, shows this principle in a most clear and obvious form. Although not specifically addressing variability, the experiment of Iver H. Iversen (2002) concerning the introduction of digital cameras into the operant chamber, is highly relevant. In the series of still pictures that Iversen included in his publication, one is from a basic experiment in extinction. A digital camera was placed inside the operant chamber and connected to an operandum, so that a picture was taken by activating it - the rat literally took selfies. The pictures taken during reinforcement show the animal in the nearly exact same position, while pictures taken during extinction show a high level of different poses and «creative» ways of pulling the chain (the operandum was a chain or stick hanging from the ceiling of the operant chamber). The photos show how the topography of the responses of the rat are uniform during reinforcement and become varied during extinction. While this is a replication of many studies done on extinction and the findings are consistent with theses studies, in the context of variability it offers an important alternative explanation to Neuringer's proposal of variability being an operant.

Neuringer's experimental work in the field of variability is outstanding and although his suggestion that variability be considered an operant is being contested in different ways, he continues to write important theoretical papers on the subject, particularly papers with reviews and summaries of the research and theory up to date. In 2002, he published an overview of the field (Neuringer, 2002), still considering variability an operant, but also going into details as to how this operant concept could be related to another concept on the same reduction level, viz *choice*.

Without going into the problems of using a term like this with its century long tradition of mentalistic connotations, Neuringer elegantly operationalized «the frequency of one response relatively to others, or response probability, to be a measure of choice or preference.» In the same paper, he goes through some parameters of variability that have been studied up to this point. Age seems to lessen variability in humans and rats, and a slight tendency for male rats to respond more varied than females overall has been recorded. Also an early onset of training variability generated a difference in later studies, found in both humans and rats. Neuringer connects variability as an operant to as varied phenomena as autism, depression, ADHD and drug effects as examples of problem areas that could benefit from the studies; self-experimentation and social behavior are also mentioned.

For a discussion of originality, Neuringer (2002) addresses three initial sources of variable behavior, for the very first occurrence that cannot have been reinforced: endogenous, noncontingent environmental events and extinction. Findings suggest that these three are preceding control by reinforcement, a general notion that also Per Holth (2012a) advocates, yet with more emphasis.

According to Neuringer (2002), *endogenous variability* is similar to base-pair changes in DNA molecules that occur spontaneously for no apparent reason and independent of external influences. In behavior, seemingly unwarranted, novel responses give an «opportunity for reinforcement to select particular levels of variation» (p. 689). *Noncontingent events* are described as chance, accidents or luck - in science it is referred to as serendipity. It is an important factor in behavior and organisms are highly sensitive to such events. *Extinction* also increases variability, as does distance in space and time to a reinforcer.

In another review paper, Neuringer (2009) compares variability to *bounded stochasticity* as being both attributes of operant behavior. Bounded stochasticity is a combination of variation and selection at work within the genome on the level of genetic variability, and Neuringer finds the process similar to variability, thus connecting the biological variability and resulting selection of genes to the behavioral variability and the resulting selection of responses. This is along the lines of

B. F. Skinners (1981) argumentation regarding the selection of operant behavior as the second of three levels of selection.

Continuing his publications of reviews, together with Greg Jensen (Neuringer & Jensen, 2012), Neuringer presents the technical terms and methodological procedures hitherto used in the experimental study of variability. There are three primary ways that experiments have been conducted: The first mentioned is *recency methods*, where reinforcement is contingent upon a sequence of responses that has not occurred in a given number of previous trials, also known as lag schedules. There are several variations of this method, and the present empiric part of this thesis facilitates one such procedure. Second is *frequency* or *threshold procedures* where reinforcement is contingent upon relatively low frequencies of responses. Running tally counters for each operandum are continually multiplied by a weighting coefficient of for example 0.95, calculated per response on other operanda, gradually decreasing the number. The numbers that fall beneath a certain threshold (for instance occurrences divided by total of all tallies), would be the ones to generate reinforcers when the related responses occurred next. One variation of this would be to reinforce only the one single response or sequence with the lowest number. Another variation is to reinforce responses according to frequency of absolute occurrence. The third kind of procedures is *statistical evaluation*, where performance is compared to a random model, generated through statistical analysis of probability. All these methods have been used in many ways by different scientists to generate data on variability.

A minor dispute on variability concerns whether the results obtained from experiments on variability should be attributed to an inborn memory, referring to some kind of rational strategy or variability generator (Page and Neuringer, 1985) or whether the same results could be found by generating stochastic responding. Machado (1997) suggested that the organism does not learn to respond at random at all, but rather *unlearns* to respond in specific ways. In his first review paper, Neuringer (2002) sketches the stochastic generator anew, but this time modify it by writing: «It is impossible to prove that an endogenous stochastic process underlies operant variability; that would

be analogous to proving the null hypothesis» (p. 692). He nonetheless still claims that the evidence as a whole is consistent with such a source, particularly by the findings of some researchers that memory for prior responses does not contribute to and can actually prevent variability.

As for the dispute on whether variability is an operant or not, in a presentation on molar and molecular analysis, with a series of photos from a session with non-contingent reinforcement, Iversen (2012) showed that a rat instantly returned to the near exact same position, and a possibly identical topography of response that occasioned the latest reinforcement (this is in accordance with the much earlier studies on «superstition» by Skinner, 1948). These photo sessions point the study of variability toward its primary connection to extinction, because they show that extinction is central in the emergence of varied responses, but with repetition as a seemingly first choice when reinforcers can in fact still be obtained (although not contingent on any particular response). Holth (2012a) says that «contingencies that permit variability but do not require it produce repetitious topographies». In a critical review of the original article by Pryor et al from 1969, Holth (2012b) also addressed this by specifying that in the experiment with the creative porpoise «(1) not only novel behavior was reinforced, (2) novel behavior was far from the only, or even the most typical, outcome, and (3) when novel behavior occurred, it typically emerged during extinction.»

Future research

In his paper from 2002, Allen Neuringer concluded with a list of possible areas of interest, related to variability and future research in this field. First of these are, naturally, diversity in the field of science, for instance implemented by self-experimentation and in the field of learning. By varying our own behavior and thoughts in everyday life, we may yield valuable information about how organisms function. On a larger scale, this applies also to social contingencies and politics. The use of negative reinforcement and resistance to change are two other fields of interest closely connected to variability, as are the comparative and human studies of attraction between the sexes: «What is the relationship between perception of variability... and emission of variable responses...?» Neuringer asks (p. 700). Other areas of future research involve attention and awareness, how

concepts are derived, play and humor, animal training, foraging theory and the issue of how variability itself can function as a reinforcement.

Two other points of interest are how different practical approaches in the use of lag schedules influence results, and how variability is actually measured, as pointed out by Barba (Barba, 2012), and also addressed by Neuringer and Jensen in the *APA Handbook of Behavior Analysis* (Neuringer & Jensen, 2013). A given lag schedule would supposedly yield different results depending on the different approaches: A schedule that demands responses only to differ from other responses (but allowing for repetition on *any* of the other operanda, say four times on a Lag 4 schedule, and counting this as fulfilling the requirement for variability on the present operandum) could be predicted to show less variability, even measured in *U*-values, than the same schedule enlarged with demands to also differ among response types (when for instance activation of *all* other available operanda are required). The experimental part of this thesis is concerned with this hypothesis, combined with possible genetically disposed differences in displaying variability, between the spontaneously hypertensive rat (SHR) and the Wistar-Kyoto strain (WKY). The second issue, of how variability is measured, is also addressed by relating incongruences arising from the use of the *U*-value.

Neuringer and others have mainly focused on the variability between sequences of responses on only two operanda demanding a similar response topography (lever press and lever press), and have measured variability by comparing whole sequences or series of responses using the general parameter of the criticised value *U*. But what would be the outcome of research if variability was measured by comparing responses within each response type (for instance lever press and chain pulling) and enlarging the possibilities of recording responses to include also absolutely new ones? This could be made possible with the photographic method of documentation suggested by Iver Iversen, supplemented with video recording. To reconnect variability with creativity and broaden the applicability of findings could possibly yield positive reactions from a wider public, especially if experiments are conducted in more free-flowing settings with specific focus on new behavior, like

in the original study by Pryor et al. The popularity of the science of behavior has suffered greatly from different public misconceptions. One is the tendency to explain behavior on mentalistic terms. Should scientists succeed in relating empirically evidenced explanations for the human behavior of creativity, as opposed to the present focus on variable repetition between operanda of already established responses, mainly in animals, it would be a valuable argument in the debate on mentalism.

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Experimental part:

Do lag schedules depending on responses or response classes yield different results,

and do genetic differences between SHR and WKY rats affect variability?

Abstract

This experiment was conducted to examine if lag schedules depending on responses or response classes yield different results. At the same time, the study facilitated two strains of rats to maintain if there would be differences in the variability recorded. The hypothesis for both issues was that differences would be evident in either changeover from baseline, between experimental phases, between groups or between the two strains used, or possibly on all these measures. Eight rats of two strains (SHR and WKY), used in a prior experiment, were subjected to Lag 3 schedules; four rats were required to respond to *any* of four operanda, the other four were required to respond to *all* of four operanda. The groups were switched after 16 sessions and run for a further 8 sessions. Data was recorded on four variability measures, as well as for responses on each operandum and reinforcers obtained. The group and strain averages of *repeated, switched, previous 2* and *previous 3* were calculated, as were the average *U-values* (see definitions of these measures on page 5). The data showed instant changes in responses on most parameters going from baseline to Phase 1. For repeated and switched it was mainly a decrease or maintaining similar levels, while for previous 2 and previous 3 it was a rapid increase, either followed by a minor reduction in Phase 2 or maintaining levels. The data also revealed differences between the two strains, but between groups the only difference found was on the measure of previous 3, and this could be ascribed to one of the strains. The *U*-values showed a high level of variability already at baseline, that kept climbing throughout both Phase 1 and Phase 2. This suggests that either prior exposure to lag schedules changes later acquisition, and/or that the measurement of *U* is not reliable as an only parameter of variability. The overall findings showed no significant differences with respect to the measures of previous 2, previous 3 and *U*, in lag schedules depending on either responses or response classes; but that higher levels of activity influence variability in genetically disposed strains.

Keywords: variability, creativity, lag schedule, SHR and WKY

Introduction

In a scientific study of creativity, the more focused and detailed research on variability is yielding interesting results in as diverse areas as animal training and models of learning (Neuringer, 2002), decision-making (Andrzejewski et al, 2005), choice (Abreu-Rodrigues et al, 2005) and ADHD (Neuringer, 2009). While disputes on definitions and use of particular concepts are not concluded within the field, particularly concerning the status of variability as an operant in its own right, researchers have long agreed that variability can be reinforced directly. Whether a discrimination-based conception of reinforcers is more or less at root (less, according to Machado and Tonneau, 2012), and what it is that is actually being reinforced as part of the concept of variability, is yet to be pinpointed. The concept itself may be too wide and too loose if not considered an operant, yet the explanations for the existing phenomenon may also well be covered by already existing theory (Holth, 2012). Other disputes concern more mundane practical matters, as to how variability is actually measured (a critique of the measure U was raised by Lourenço de Souza Barba, 2012), and how genetical factors impede on the research (Hunziker, Saldana and Neuringer, 1996). It is the last point that is being experimentaly adressed in this thesis, together with how differences in requirements of lag schedules are possibly leading to differing results. It is worth pointing out that this has become interesting because different studies have, indeed, used different definitions of lag schedules (see for instance the schedules with only two operanda used by Page and Neuringer, 1985, versus the multiple choice schedules used by Lee et al, 2002).

Since the phenomenon of variability is established as occuring lawfully, albeit not yet placed in its final conceptual and methodological context (David C. Palmer, 2012 and M. Jackson Marr, 2012), and since its importance relating to human affairs cannot be understated, particularly concerning creativity overall (Karen Pryor, Richard Haag & Joseph O'Reilly, 1969), the circumvention of undesirable effects of extinction (Allen Neuringer, 2012), learning (Allen Neuringer, Chris Deiss & Gene Olson, 2000), and possible treatment or at least easement of ADHD, autism and general problem behavior (Ronald Lee, Jennifer J. McComas & Jennifer Jawor, 2002), it

is pertinent to continue the research and establish more empirical data.

This experiment was conducted to examine if a difference occurs when using a lag schedule demanding previous responses to occur on *any* operandum versus on *all* operanda, id est: Do lag schedules depending on responses or response classes yield different results? At the same time, the study facilitated two strains of rats, previously used in similar research, to maintain if there would be notable differences, possibly based on genetic factors, in the variability registered, id est: Do genetic differences between SHR and WKY rats affect variability? This question is relevant because differences between these strains are in many ways similar to the differences between children diagnosed with ADHD and normally developing children (Sagvolden, 2000), and research can help us understand these matters better. For both questions, the hypothesis was that a difference would be evident in either changeover from baseline, between groups or between the two strains used, or possibly on all these measures.

Method

Subjects

Four male spontaneously hypertensive rats (SHR) and four male Wistar-Kyoto rats (WKY) were obtained from Charles River, Germany, at arrival weighing on average 150 g. The animals were subjected to magazine training for five days, after three days of habituation to their new environment. Prior to the present study, subjects then participated in an experiment with first increasing and then decreasing lag schedules, at the end of which they were on a Lag 0 schedule.

For storage, each rat was housed individually in a home-cage: A plastic box with a lid made of stainless steel rods. The boxes were sized according to standard governmental regulations, 25 cm (width) x 40 cm (length) x 20 cm (height), and equipped with sawdust and a medium sized red-colored tube for the rat to hide in. The boxes were cleaned and the sawdust changed once a week. Outside experiments, all boxes were contained in a larger air conditioned movable unit, maintained at a temperature between 20° C and 25° C (average 21° C) and within a humidity of 23 % to 35 % (average 30 %).

The animals were placed on a 21 to 22 hour water deprivation schedule, with water freely available for 1 hour per day after every session. Food was freely available, except during sessions. A 12:12 hr light/dark cycle was maintained throughout, with experimental sessions occurring during the light phase, seven days a week. At the beginning of the experiment, the average weight of the rats was 294 g, ranging from 274 g to 310 g.

The subjects were handled with gloves throughout the experiment.

Apparatus

The experiment utilized four modified operant conditioning chambers from Campden Instruments Ltd., sized 24 cm (width) x 19 cm (height) x 23 cm (depth), with the back and front walls made of clear Plexiglas and the ceiling and sides made of aluminum. The floor was made of wire bars 1 cm apart, above a removable tray containing odorless sawdust. The front could be opened for handling the animals. The left wall had two response levers, left (L) and right (R), 11 cm apart, each 4 cm wide, 1 cm high and protruding 1.5 cm, that each activated a micro switch when pressed down with a weight of 8 g; and a square opening of 4.5 cm x 4 cm, between the two levers, for delivery of water. Two response chains (on average at a length of 10 cm) were hanging from the ceiling 7 cm from the left wall and 9 cm apart, that each activated a micro switch when pulled down with a force of between 2 g and 6 g. The micro switches relayed activation for recording.

The chambers were connected to each their laptop computer (HP-Compaq nx9420 with Microsoft XP SP3 operative system) through an ADU208 ONTRAK USB Relay I/O Interface, and programs for control of contingencies and recording of data were written in Visual Basic.

A 2.8 W lamp in the ceiling provided houselight, and two small LED lamps situated on the top right wall provided infrared light for filming when the chamber was in darkness.

A small web camera was connected to another computer for observation and video recording of the sessions. The camera was placed in the ceiling in the middle of the right side of the chamber.

Each chamber was contained in a sound- and light-attenuating cubicle 68 cm (width) x 49 cm (height) x 43 cm (depth), with protruding wire connections to computers and power sources.

Procedure and design

Data from the prior experiment conducted with the same animals were obtained, and data points from the last seven days of that experiment were used as baseline for the present study and are included in all graphs. Related threats to validity are treated later in this thesis.

In the present experiment, there were two experimental conditions, both being a Lag 3 contingency. In the first condition, the *Neuringer schedule*, the animals were required to have elicited three previous responses on *any* other operandum for the present response to lead to reinforcement. In the second condition, the *Holth schedule*, the animals were required to have elicited three previous responses on *all* other operanda at least once, for the present response to lead to reinforcement.

The study was divided into baseline and two experimental phases. At the beginning of Phase 1, half of the SHRs and half of the WKYs were randomly selected for Group 1 and the other half of both strains for Group 2. In Phase 1, running for 16 days, Group 1 was put on the Holth-schedule, and Group 2 on the Neuringer-schedule. In Phase 2, running for eight days, conditions were inversed: Group 1 was put on the Neuringer-schedule, and Group 2 on the Holth-schedule.

Daily sessions lasted 30 minutes, initiated by illumination of the houselight. Approximately 0.03 ml of water was delivered upon correct responding according to schedule.

The study was a randomized group design. However, since data was collected on a continuous basis (and not only at the beginning and end of the experiment), and since calculations and presentation of results are done also on a molecular level for each subject, the study is also to be considered a single-subject design, with three immediate replications under each condition (Alan E. Kazdin, 2011).

Data analysis

The main dependent variables for measurement of variability were *repeated* (number of repetitions on same operandum), *switched* (number of switches between two operanda), *previous 2* (number of series of three responses on three different operanda) *previous 3* (number of series of

four responses on four different operanda). Also recorded were all responses on each operandum separately, and total of reinforcers obtained (averages for each group are enclosed in Tables 2 and 4, and comparisons between groups and strains are enclosed in Table 6).

In accordance with the suggestions by Philip N. Hineline (2001) to include both a molar and a molecular analysis of behavioral momentum, the data has been treated statistically as well as cumulatively, and is being presented graphically as well as numerically. For a mere presentation of effect, a visual inspection of the enclosed graphs will suffice and at the same time reveal developments within each experimental condition, where as a mathematical calculation on individual scores and averages will reveal possible statistically significant findings (Murray Sidman, 1960).

All data on variability from each rat have therefore been computed individually and are presented graphically in Figures 1 to 8. Averages of variability data from each subject in each group and averages of number of responses on each operandum and number of reinforcers obtained by each subject in each group (referred to as *other data*) were calculated and are enclosed in Tables 1 to 4. Averages of variability data and of other data from each group and from each strain were also calculated and are displayed in Tables 5 and 6.

The mean *U*-values for distribution of responses along the four operanda during baseline and the two experimental phases were calculated for each group and for each strain (and are enclosed numerically in Table 7), according to the equation: $U = -\sum^4_1 [RF_i \times \log_2(RF_i)] / \log_2(4)$.

For malfunctions of levers, chains and computers, when occurring during sessions, the relevant data obtained was excluded from the dataset, both for the individual subject and for the statistical calculations on group level. Exclusions due to malfunctions were: 3983 WKY session 60; 3985 WKY session 68 and 77; 3988 WKY session 65 and 75; 3989 SHR session 68 and 76.

Numbers given in parenthesis are displaying data: (*Baseline, Phase 1, Phase 2*).

Results

A visual inspection of the graphs in Figures 1 through 8 will reveal that the variability

measures of repeated and switched for all animals are showing a pattern of gradual decline throughout both experimental phases. At the same time, the variability measures of previous 2 and previous 3 for Group 1 are showing a tendency for previous 3 to be slightly more elevated in Phase 1 and maintaining this higher level throughout Phase 2, whereas for Group 2, previous 2 measures are higher than previous 3 in Phase 1, changing places in Phase 2.

Group 1

Average variability data obtained from each subject in Group 1 (order of experimental conditions: Holth-schedule, Neuringer-schedule), is enclosed in Table 1 and runs as follows:

Subject 3982 SHR (Figure 1) showed an increase in repetitions at the beginning of Phase 1 as compared to baseline, but reclined and stayed at the same level during the end of Phase 1 and throughout Phase 2 (73, 88, 74). The same general pattern is recorded for switching, but with averages falling below baseline in Phase 2 (109, 127, 90). Both previous 2 (57, 198, 172) and previous 3 (42, 202, 186) showed rapid increase at introduction of the Holth schedule in Phase 1 with a slight depression of both measures in Phase 2. Previous 3 was occurring more often than previous 2 in both phases. General level of responses was above 100 for all parameters.

Subject 3983 WKY (Figure 2) had a marked difference between repeated (53, 49, 36) and switched (118, 56, 54) at baseline, with a preference for switching at more than double the rate of repetition. Both measures declined during the experimental phases, to a level below 100 responses for both parameters. Previous 2 (44, 116, 93) increased in Phase 1 and declined in Phase 2, but was still at more than double the baseline. Previous 3 (19, 149, 153) showed a large incline at Phase 1, kept climbing in Phase 2, and was overall higher than previous 2.

Subject 3984 SHR (Figure 3) had a relatively similar pattern of responses on repeated (115, 105, 72) and switched (97, 92, 69); both measures declined during experimental phases, while previous 2 (75, 192, 163) and previous 3 (33, 221, 207) followed the pattern of a large increase in Phase 1 and a minor depression in Phase 2. Previous 3 was higher than previous 2 in both phases. Level of responses was generally very high: above 200 for both previous and around 100 for

repeated and switched (yet falling).

Subject 3985 WKY (Figure 4) showed a small increase in repeated responses from baseline to Phase 1, declining in Phase 2 (32, 40, 36). Else, the same pattern as displayed by the other subjects in Group 1 was manifest: Switched (95, 31, 26) declined, while previous 2 (26, 68, 65) and previous 3 (12, 76, 90) inclined, the latter being at the highest level. General level of responses was very low (below 100 for repeated and switched, and below 150 for previous 2 and previous 3).

Group 2

Average variability data obtained from each subject in Group 2 (order of experimental conditions: Neuringer-schedule, Holth-schedule), is enclosed in Table 2 and runs as follows:

Subject 3986 WKY (Figure 5) maintained a steady level of repeated responses (50, 52, 45) while declining in number of switched (129, 67, 58). Both previous 2 (54, 119, 131) and previous 3 (29, 115, 144) inclined rapidly at Phase 1 and maintained levels during Phase 2 with a slight statistical increase. Previous 2 was showing a statistical higher level than previous 3 in Phase 2; this was reversed in Phase 2. The level of responses overall was low.

Subject 3987 SHR (Figure 6) also maintained steady levels of repeated (103, 97, 103), while switched (113, 86, 54) declined to half over the two phases. From a low level of baseline, previous 2 (25, 153, 146) showed a six times higher number during Phase 1 and stayed at this level in Phase 2. For previous 3 (10, 80, 151) a similar incline took place, leveling previous 2 and 3 in Phase 2. The level of responses for previous 2 was high (above 150). In Phase 2, previous 3 also gained a high level of responding.

Subject 3988 WKY (Figure 7) had a decline in repeated (67, 54, 47) and switched (104, 76, 61), and a detrimental increase in the number of previous 2 (40, 98, 109) and previous 3 (12, 82, 113). Previous 3 became more prominent during Phase 1 and eventually gained a higher level than previous 2 in Phase 2. General level of responses was medium (below 150).

Subject 3989 SHR (Figure 8) showed an incline in repeated (60, 83, 95), but like the rest of this group, also declined on switched (141, 105, 75). In Phase 1, previous 2 (37, 195, 139) became

prominent, while in Phase 2, previous 3 (24, 132, 206) occurred more often. This is the only subject to show a clear switch between previous 2 and previous 3 when changing conditions. The overall level of responses is very high (above 150).

Intergroup statistics

Visual inspection of the graphs (Figure 9) and statistical calculations (Table 5) for the average variability measures in each group show the following: Repetition is close to the same throughout all conditions, with a small decline in Group 1 (68, 71, 55) at the end of Phase 2, but stable for Group 2 (70, 72, 72). Switching on average declined over both phases, for both Group 1 (105, 78, 61) and Group 2 (122, 83, 61). Previous 2, initially low during baseline, nearly tripled in Phase 1, before declining a little in Phase 2 for Group 1 (50, 145, 125); the same pattern was seen in Group 2 (39, 142, 131). Previous 3, also very low from onset, showed a marked difference between the groups in Phase 1, with Group 1 (26, 162, 162) displaying well above Group 2 (19, 103, 151). The difference lessens in Phase 2, where the level over time declines a little for Group 1 and inclines for Group 2 (this can only be seen on the graph, not on the statistics). Both groups increase levels on previous 3 to more than five times the level of baseline.

A measure of effect outside variability was calculated by comparing reinforcers delivered in the two groups on average (Figure 9, bottom left, and Table 6). After a decrement during Phase 1, Group 1 (254, 181, 211) obtained more reinforcers than Group 2 (248, 175, 155), but neither group returned to the number of reinforcers obtained at baseline.

Another measure outside variability was obtained by registration of each operandum for each subject. The average responses during baseline and each experimental phase are presented in Table 2 (Group 1) and Table 4 (Group 2), and show that in general subjects prefered the left lever, closely followed by the right lever; the use of chains often increased during both phases, but never exceeded the use of the levers. On group averages there are only small differences: In Group 1 the left lever (103, 134, 114) increased in Phase 1 and decreased in Phase 2, as did also right lever (85, 133, 111). The same happened in Group 2 for the left lever (122, 131, 111) and the right lever (89,

136, 132). For Group 1 the average use of the left chain (34, 89, 78) more than doubled, and the use of the right chain tripled (31, 104, 99). For Group 2 both left chain (14, 55, 78) and right chain (24, 79, 98) were more than four times baseline at Phase 2.

Strain statistics

In a visual inspection of the averages of strains, (two subjects of each strain from each group), nearly all variability measures show marked differences between SHR and WKY (Figure 9 and Table 5). Except for baseline on switched, the SHR strain have higher scores on all parameters, in general twice as much. For both strains, findings are relatively similar to groups on the following: Repeated (SHR 88, 93, 86 - WKY 50, 49, 42) was more or less stable throughout, switched (SHR 115, 102, 72 - WKY 112, 57, 51) was declining over both phases, previous 2 (SHR 48, 185, 156 - WKY 41, 100, 101) and previous 3 (SHR 27, 159, 186 - WKY 18, 105, 126) were both inclining rapidly in Phase 1 and maintained levels in Phase 2. Both strains obtained less reinforcers during both phases than during baseline (Table 6).

U-**measures**

The *U*-values calculated for the average distribution of responses between the four different operanda within each group and each strain (Table 7), are showing an increase in all categories throughout the experiment, beginning on a relatively high level at baseline and ending near the topmark in Phase 2. Both Group 1 (-0.90837, -0.98935, -0.99257) and Group 2 (-0.79680, -0.95559, -0.98721) increased the variability of their responses, when measured this way, at both Phase 1 and Phase 2. The same is found for the strain of SHR (-0.84109, -0.97198, -0.98631) and the strain of WKY (-0.88067, -0.98383, -0.99304). For all categories the largest increase occurred from baseline to Phase 1.

Discussion

Major findings in this study were that the supposed differences with respect to the measures of previous 2, previous 3, and *U*, between two types of lag schedules, were miniscule and could be explained by strain differences; genetic factors do influence variability. For the main question

whether different result would come from using a lag schedule demanding previous responses to occur on *any* operandum versus on *all* operanda, it seems that the data is slightly ambiguous. The only significant differences obtained in the variability measures in this experiment were on previous 3 in Phase 1, and this was to be expected. Since the requirement for Group 1 was to visit *all* other operanda for reinforcement to occur (not allowing for repetition), and for Group 2 to visit *any* operanda for the required number of times (thus allowing for repetition), the finding was not surprising. What is ambiguous is that in Phase 2, the contingencies were reversed but the groups did not display any significant change (only one out of eight subjects showed the anticipated shift between previous 2 and previous 3 in Phase 2). Instead of Group 1 becoming more lax and responding to the new contingencies that allowed for repetitions, the group maintained its level of variability. It did however display a decrease in previous 3 during the very last few sessions of the experiment. It can be speculated that a further eight sessions or more would eventually have shown contact with the Neuringer-schedule for all subjects in this group. Group 2 on average responded as would be expected and achieved a higher number of previous 3 in Phase 2, when put on the Holth-schedule. But when looking at the individual results it is actually only the two subjects, 3987 SHR and 3989 SHR that display these results, raising the average for the group to its level in Phase 2. This concurs with the findings on the second question, concerning the genetic differences between SHR and WKY rats when testing for variability, but renders the main issue of this thesis still void. It cannot be established that the difference found in previous 3, Phase 1 are due to the lagschedules in effect, and the hypothesis of lag schedules depending on responses or response classes yielding different results, is not sustained and so far still in dispute.

The incongruence occurring between the *U*-values increasing over both Phase 1 and Phase 2, versus the general pattern of the variability measures of previous 2 and previous 3 showing a decline on most parameters in Phase 2, is to be explained by the differing mathematical calculations, not as a factual discrepancy. The incongruence is none the less of importance to the discussion concerning the use of the *U*-value as an arbitrary and possibly misleading measure of

variability (Barba, 2012); it will take a longer running replication of this experiment to maintain if this claim holds true. As for measures of variability that are mathematically less complicated (and possibly more intuitively in accord with what actually occurs inside the operant chamber), the four measures of repeated, switched, previous 2 and previous 3 have been used as the basis for observations and calculations in this study; the U-value being a supplement only. For a scientific purpose, to measure a phenomenon over more than one variable and if at all possible, over more than one category of measurement, is highly recommended in classical literature (Francis Bacon, 1902), as well as in modern textbooks (Kazdin, 2011); as the measure of U may be a fine supplement, it should not be used as the only parameter on variability. When that has been said, the learning history of each subject may be a major confounding factor in this experiment and the U-value is the only mathematically established measurement that unveils this clearly.

For the other part of the hypothesized claims of this experiment, to maintain if there would be notable differences based on genetic factors, in the variability registered, SHRs showed a general higher level of activity overall than the WKYs (see Figure 9). On all measures of both variability and other data, SHRs are close to or above having the double number of responses compared to the WKYs. It can be concluded that the present thesis supports the notion of genetical differences in species to account for factors of variability, especially with a focus on species or strains that have a high level of activity from the outset. More activity seems to lead to more diversity.

Concerning reinforcement, all subjects obtained fewer reinforcers during experimental phases, compared to baseline. This was to be expected, as all sessions, also at baseline, lasted for 30 minutes and number of required responses for obtaining reinforcement was effectively as a minimum quadrupled during experimental phases (from a Lag 0 schedule, reinforcing every response, to a Lag 4 schedule, in effect and at best, possibly reinforcing every fourth response). Similar results have been found in research with intermittent schedules of all kinds (see for instance C. B. Ferster and B. F. Skinner, 1957), and were to be anticipated.

There are some issues regarding the validity of the study: The experiment conducted prior to

the present, with the same two strains of rats, implemented a gradual increase in lag schedules

followed by a decrease to Lag 0 (in effect continuous reinforcement). The same operanda were used

as in the present experiment. The previous experiment naturally poses a threat to the validity of the

findings in this study, in the form of the established learning history for each subject involved. This

is not evident in the basic variability measurements (repeated, switched, previous 2 and previous 3),

but is rather visible in the calculated U-measure. The subjects all displayed a much higher level of

variability according to this measurement, than would be expected (see Table 7 for details).

Although it can be disputed that a value of -0.50 U does not necessarily convey a distribution

midway between totally varied and totally repetitive responses (as pointed out by Barba, 2012), it

could none the less be expected to be somewhere around this number at the outset of an experiment,

and in the present study, it is not. Numbers at baseline range from -0.79 to -0.90. Ecobiological

factors as to the response cost per activated operandum may influence the variability, and could

account for at least part of the discrepancy: The registered preference of the levers at the expense of

the chains seems to indicate this. A preference is however counterintuitive to a higher level of

variability: It opposes the expectation that a naive rat investigating new surroundings would draw

on all possibilities at the outset. However, as the experiment conducted prior to the present

introduced the subjects to lag schedules, and since it can be suspected that a batch of naive subjects

would react differently to the Holth- and Neuringer-schedules at a first encounter, and possibly

yield different results, the present experiment cannot claim indifference to this question. For

resolving whether familiarity with lag schedules influences the speed of transition between them,

possibly also influencing the previous 3 measurement under the two different experimental

approaches, and perhaps also lowering the U-value at baseline, a replication with naive animals is

required.

    Other possible threats to validity include noises from ongoing repairs in the building, the at

times stressful handling of each subject when transferred from home-cage to experimental chamber

and malfunctions of equipment, either in experimental chambers or on computers. Concerning the

noises, all subjects were exposed to the same levels of disturbance and in connection with the

randomization into groups it should be disregarded as lowering the total number of responses for all

subjects if having any effect at all, and not affecting inter-group comparisons. Handling of the

subjects were in general done without any implications, but the SHRs tended to bite the

experimenter, and on occasion were handled swiftly and possibly stressful. Particularly, subject

3987 SHR was thus handled at the end of session 66, which could explain the sudden dives in

responses on previous 2 and 3 occurring in the following session 67 (see Figure 6). However, since

it cannot be established that the handling was actually causal, the data from this session has not

been excluded. Concerning malfunctions of levers, chains and computers, when occurring during

sessions, to prevent distortion the relevant data have been excluded from the dataset, both for the

individual subject and for the statistical calculations on group level. The relevant exclusions are

detailed in the previous section on data analysis.

The differences in level of variability between the strains may have relevance in the study of

ADHD. This study established that SHRs show more variability overall than WKYs, likely as a

direct function of their heightened level of activity. In a human context, people diagnosed with

ADHD may also be expected to attain higher levels of varied behavior, measured on any parameter,

than their respective peers without diagnosis. Although doubtful that this will have any pertinence

when it comes to the treatment of ADHD, it could still facilitate alternative ways of accepting this

seemingly genetic deficiency, focusing on the positive attributes that varied behavior brings with it

(in terms of creativity and problem solving).

Since it is possible that transitions between steps on intermittent reinforcement and lag

schedules take longer when coming down than when going up, it would be of value to replicate the

present experiment and let Phase 2 run over a longer period of time, with at least as many sessions

as in Phase 1. A replication should also be done with naive subjects of the same strain to determine

more thoroughly if there is a factual difference between requirements for response versus response

class in lag schedules, excluding the confounding occurring as a result of strain differences.

Conclusion

This experiment found no difference with respect to measurements of variability between lag schedules depending on responses on *any* versus on *all* operanda, but did establish that higher levels of activity, possibly genetically disposed, influences variability.

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Table 1

Average variability data from each subject in Group 1

3982 SHR			
Measure	Baseline	Phase 1	Phase 2
Repeated	73	88	74
Switched	109	127	90
Previous 2	57	198	172
Previous 3	42	202	186

3983 WKY			
Measure	Baseline	Phase 1	Phase 2
Repeated	53	49	36
Switched	118	56	54
Previous 2	44	116	93
Previous 3	19	149	153

3984 SHR			
Measure	Baseline	Phase 1	Phase 2
Repeated	115	105	72
Switched	97	92	69
Previous 2	75	192	163
Previous 3	33	221	207

3985 WKY			
Measure	Baseline	Phase 1	Phase 2
Repeated	32	40	36
Switched	95	31	26
Previous 2	26	68	65
Previous 3	12	76	90

Note. For Group 1, a Lag 3 Holth-schedule with the criterion of all other three operanda visited was implemented in Phase 1. A Lag 3 Neuringer-schedule with the criterion of any other operandum visited three times was implemented in Phase 2.

Table 2

Average other data from each subject in Group 1

3982 SHR			
Measure	Baseline	Phase 1	Phase 2
Left lever	111	179	150
Right lever	104	183	151
Left chain	30	106	98
Right chain	39	150	122
Reinforcers	284	223	261

3983 WKY			
Measure	Baseline	Phase 1	Phase 2
Left lever	85	107	90
Right lever	73	96	76
Left chain	61	85	83
Right chain	18	85	87
Reinforcers	238	153	185

3984 SHR			
Measure	Baseline	Phase 1	Phase 2
Left lever	146	173	140
Right lever	90	185	154
Left chain	27	126	94
Right chain	61	129	123
Reinforcers	323	244	264

3985 WKY			
Measure	Baseline	Phase 1	Phase 2
Left lever	71	71	69
Right lever	74	61	55
Left chain	17	38	32
Right chain	8	50	61
Reinforcers	170	90	118

Note. For Group 1, a Lag 3 Holth-schedule with the criterion of all other three operanda visited was implemented in Phase 1. A Lag 3 Neuringer-schedule with the criterion of any other operandum visited three times was implemented in Phase 2.

Table 3

Average variability data from each subject in Group 2

	3986 WKY		
Measure	Baseline	Phase 1	Phase 2
Repeated	50	52	45
Switched	129	67	58
Previous 2	54	119	131
Previous 3	29	115	144

	3987 SHR		
Measure	Baseline	Phase 1	Phase 2
Repeated	103	97	103
Switched	113	86	54
Previous 2	25	153	146
Previous 3	10	80	151

	3988 WKY		
Measure	Baseline	Phase 1	Phase 2
Repeated	67	54	47
Switched	104	76	61
Previous 2	40	98	109
Previous 3	12	82	113

	3989 SHR		
Measure	Baseline	Phase 1	Phase 2
Repeated	60	83	95
Switched	141	105	75
Previous 2	37	195	139
Previous 3	24	132	206

Note. For Group 2, a Lag 3 Neuringer-schedule with the criterion of any other operandum visited three times was implemented in Phase 1. A Lag 3 Holth-schedule with the criterion of all other three operanda visited was implemented in Phase 2.

Table 4

Average other data from each subject in Group 2

3986 WKY

Measure	Baseline	Phase 1	Phase 2
Left lever	102	106	99
Right lever	96	110	117
Left chain	22	58	69
Right chain	42	80	97
Reinforcers	262	174	148

3987 SHR

Measure	Baseline	Phase 1	Phase 2
Left lever	154	148	118
Right lever	77	155	158
Left chain	7	38	76
Right chain	12	75	105
Reinforcers	250	184	155

3988 WKY

Measure	Baseline	Phase 1	Phase 2
Left lever	123	103	99
Right lever	69	93	82
Left chain	7	40	61
Right chain	23	74	93
Reinforcers	223	99	117

3989 SHR

Measure	Baseline	Phase 1	Phase 2
Left lever	107	167	134
Right lever	113	182	175
Left chain	19	82	113
Right chain	17	84	98
Reinforcers	257	237	210

Note. For Group 2, a Lag 3 Neuringer-schedule with the criterion of any other operandum visited three times was implemented in Phase 1. A Lag 3 Holth-schedule with the criterion of all other three operanda visited was implemented in Phase 2.

Table 5

Average variability data from groups and strains

Group 1			
Measure	Baseline	Phase 1	Phase 2
Repeated	68	71	55
Switched	105	78	61
Previous 2	50	145	125
Previous 3	26	162	162

Group 2			
Measure	Baseline	Phase 1	Phase 2
Repeated	70	72	72
Switched	122	83	61
Previous 2	39	142	131
Previous 3	19	103	151

Strain SHR			
Measure	Baseline	Phase 1	Phase 2
Repeated	88	93	86
Switched	115	102	72
Previous 2	48	185	156
Previous 3	27	159	186

Strain WKY			
Measure	Baseline	Phase 1	Phase 2
Repeated	50	49	42
Switched	112	57	51
Previous 2	41	100	101
Previous 3	18	105	126

Note. In Group 1, a Lag 3 Holth-schedule was implemented in Phase 1 and a Lag 3 Neuringer-schedule in Phase 2. In Group 2, the order of the schedules was the opposite. The strains were distributed equally between both groups.

Table 6

Average other data from groups and strains

Group 1			
Measure	Baseline	Phase 1	Phase 2
Left lever	103	134	114
Right lever	85	133	111
Left chain	34	89	78
Right chain	31	104	99
Reinforcers	254	181	211

Group 2			
Measure	Baseline	Phase 1	Phase 2
Left lever	122	131	111
Right lever	89	136	132
Left chain	14	55	78
Right chain	24	79	98
Reinforcers	248	175	155

Strain SHR			
Measure	Baseline	Phase 1	Phase 2
Left lever	130	167	136
Right lever	96	176	159
Left chain	21	88	94
Right chain	32	110	113
Reinforcers	279	222	223

Strain WKY			
Measure	Baseline	Phase 1	Phase 2
Left lever	95	97	90
Right lever	78	90	84
Left chain	27	55	62
Right chain	23	72	86
Reinforcers	223	131	143

Note. In Group 1, a Lag 3 Holth-schedule was implemented in Phase 1 and a Lag 3 Neuringer-schedule in Phase 2. In Group 2, the order of the schedules was the opposite. The strains were distributed equally between both groups.

Table 7

U-values for distribution of responses on four operanda for each group and strain

| | *U*-values | | |
Category	Baseline	Phase 1	Phase 2
Group 1	-0.90837	-0.98935	-0.99257
Group 2	-0.79680	-0.95559	-0.98721
Strain SHR	-0.84109	-0.97198	-0.98631
Strain WKY	-0.88067	-0.98383	-0.99304

Note. *U*-values were calculated by the equation: $U = -\sum_{1}^{4} [RF_i \times \log_2(RF_i)] / \log_2(4)$, based on the data in Table 6. The values represent relative degrees of variability on distribution of responses on all operanda, on a scale from 0 to -1.
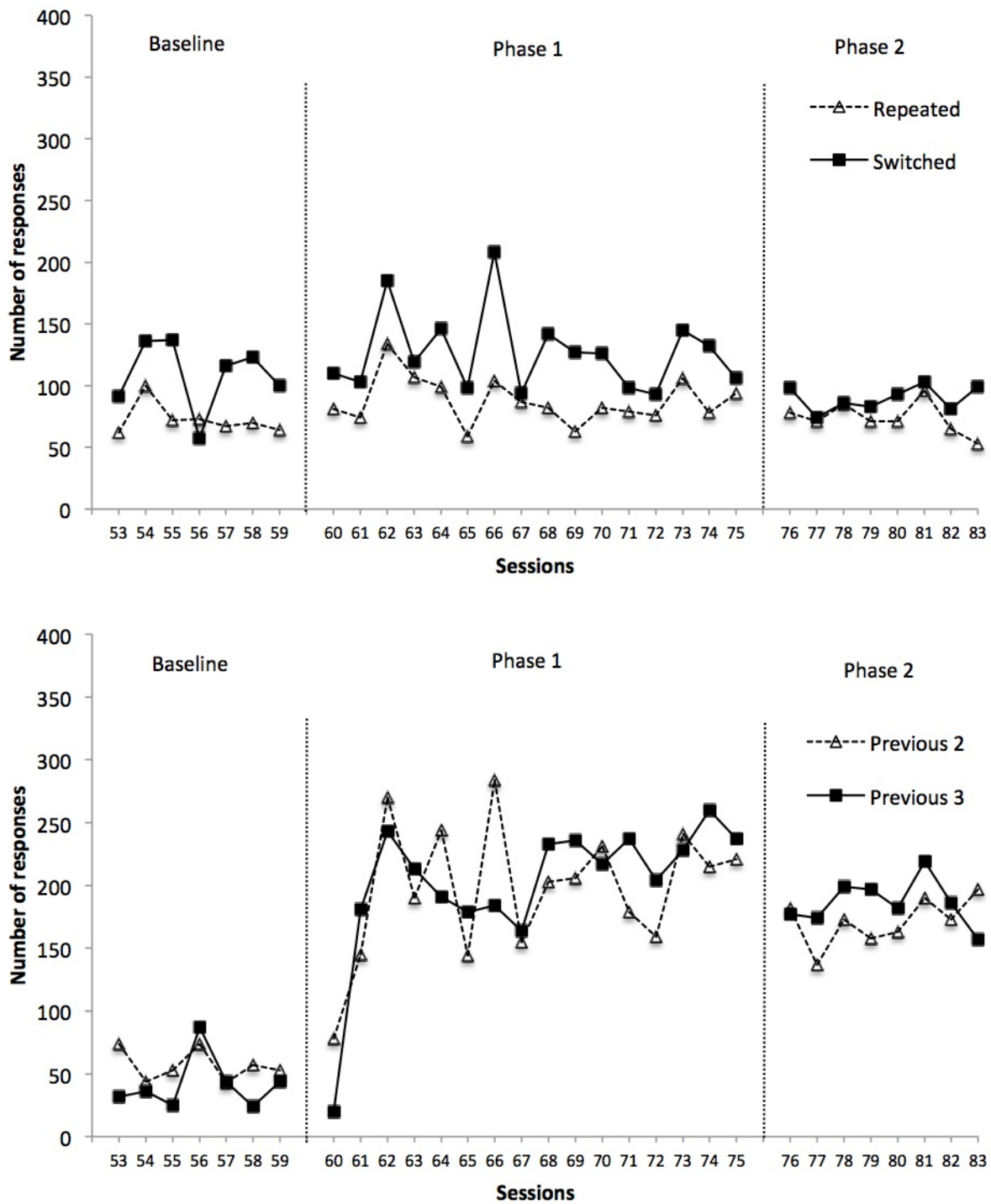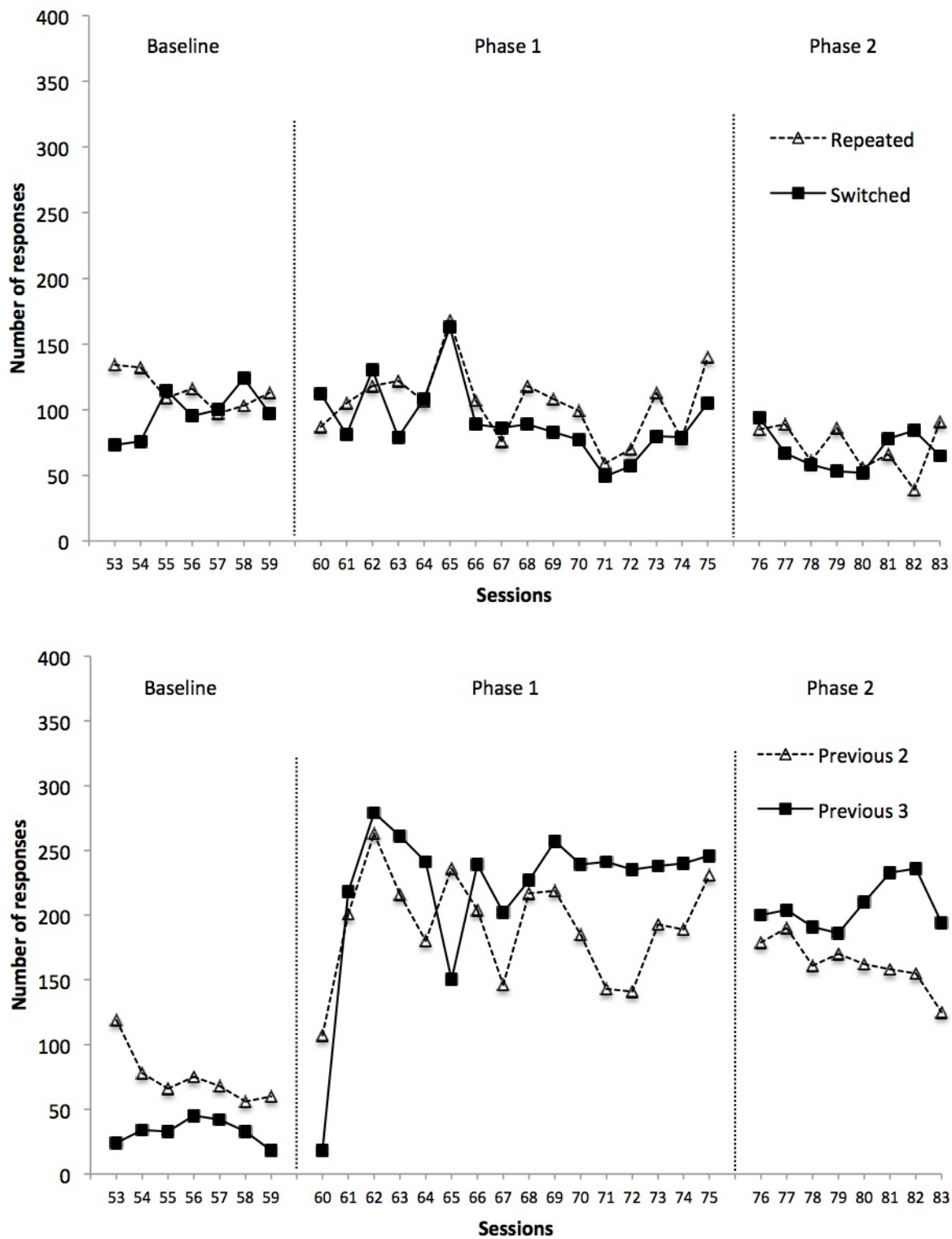
Figure 1. Variability data presented graphically for subject 3982 SHR (Holth-Neuringer). The upper graph displays number of responses per session of repeated (one operandum activated) and switched (two operanda activated). The lower graph displays number of responses of previous 2 (three operanda activated) and previous 3 (four operanda activated). Phase 1 was a Lag 3 Holth-schedule with the criterion of *all* other three operanda visited; Phase 2 was a Lag 3 Neuringer-schedule with the criterion of *any* other operandum visited three times.
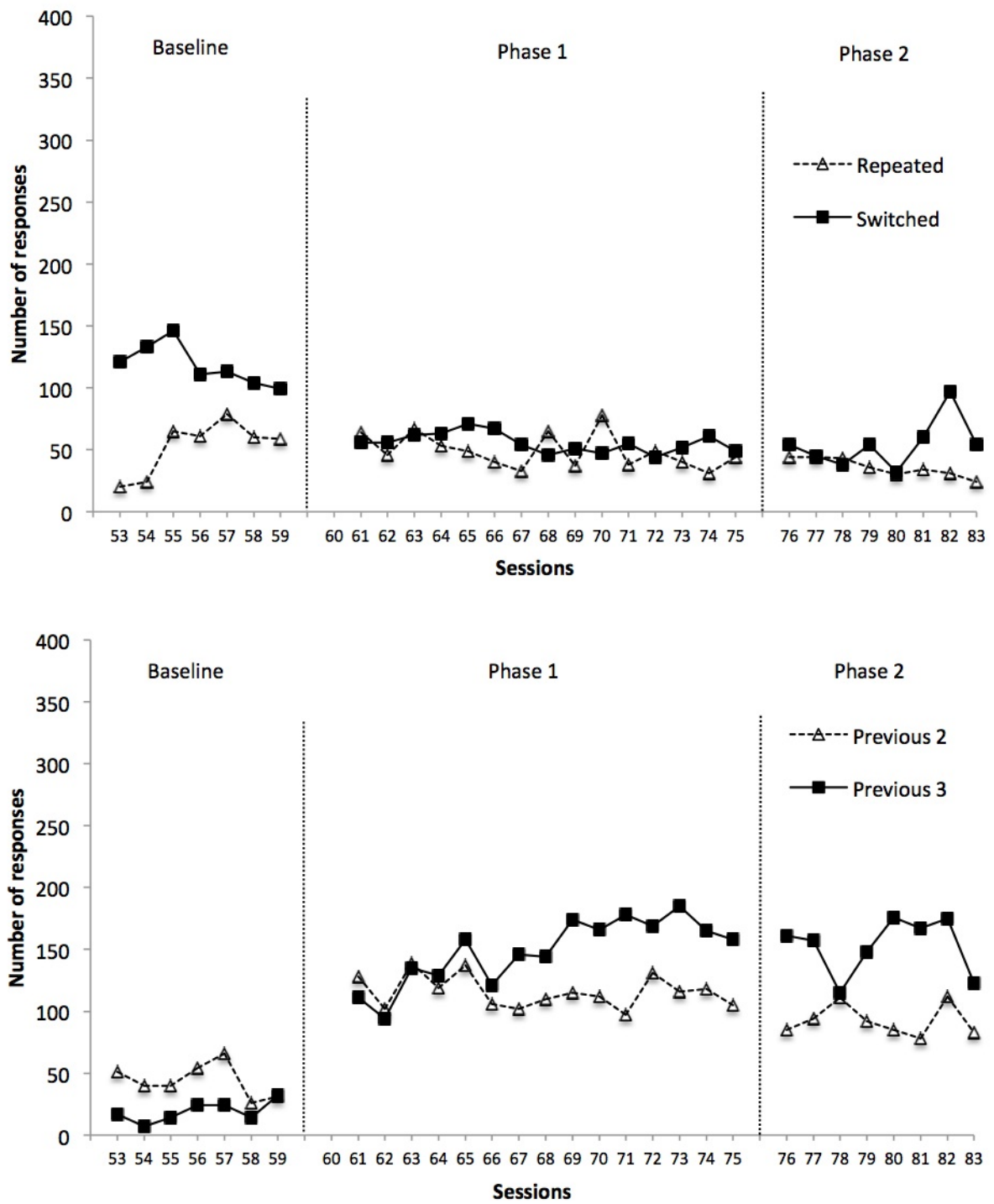
Figure 2. Variability data presented graphically for subject 3983 WKY (Holth-Neuringer). The upper graph displays number of responses per session of repeated (one operandum activated) and switched (two operanda activated). The lower graph displays number of responses of previous 2 (three operanda activated) and previous 3 (four operanda activated). Phase 1 was a Lag 3 Holth-schedule with the criterion of *all* other three operanda visited; Phase 2 was a Lag 3 Neuringer-schedule with the criterion of *any* other operandum visited three times.
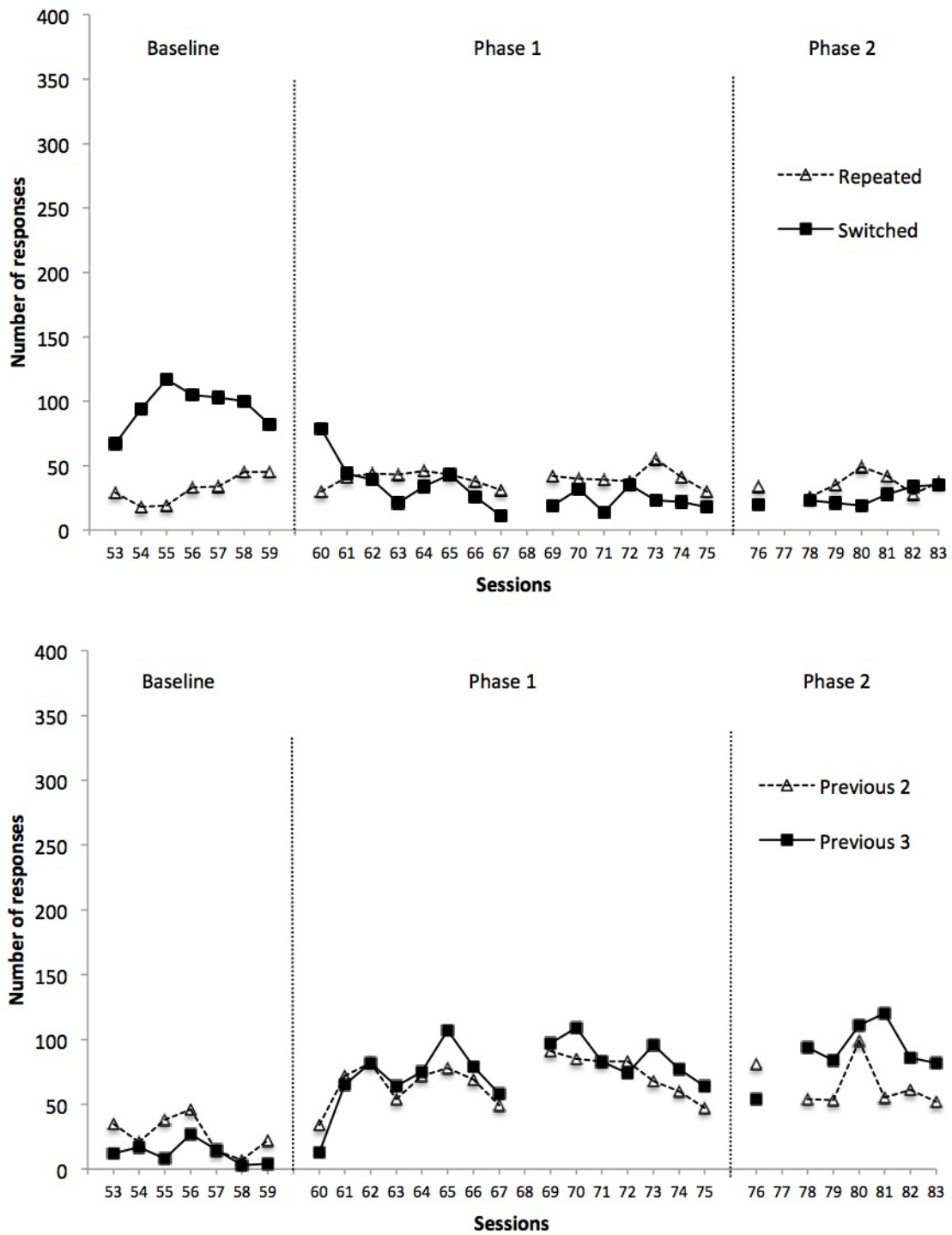
Figure 3. Variability data presented graphically for subject 3984 SHR (Holth-Neuringer). The upper graph displays number of responses per session of repeated (one operandum activated) and switched (two operanda activated). The lower graph displays number of responses of previous 2 (three operanda activated) and previous 3 (four operanda activated). Phase 1 was a Lag 3 Holth-schedule with the criterion of *all* other three operanda visited; Phase 2 was a Lag 3 Neuringer-schedule with the criterion of *any* other operandum visited three times.
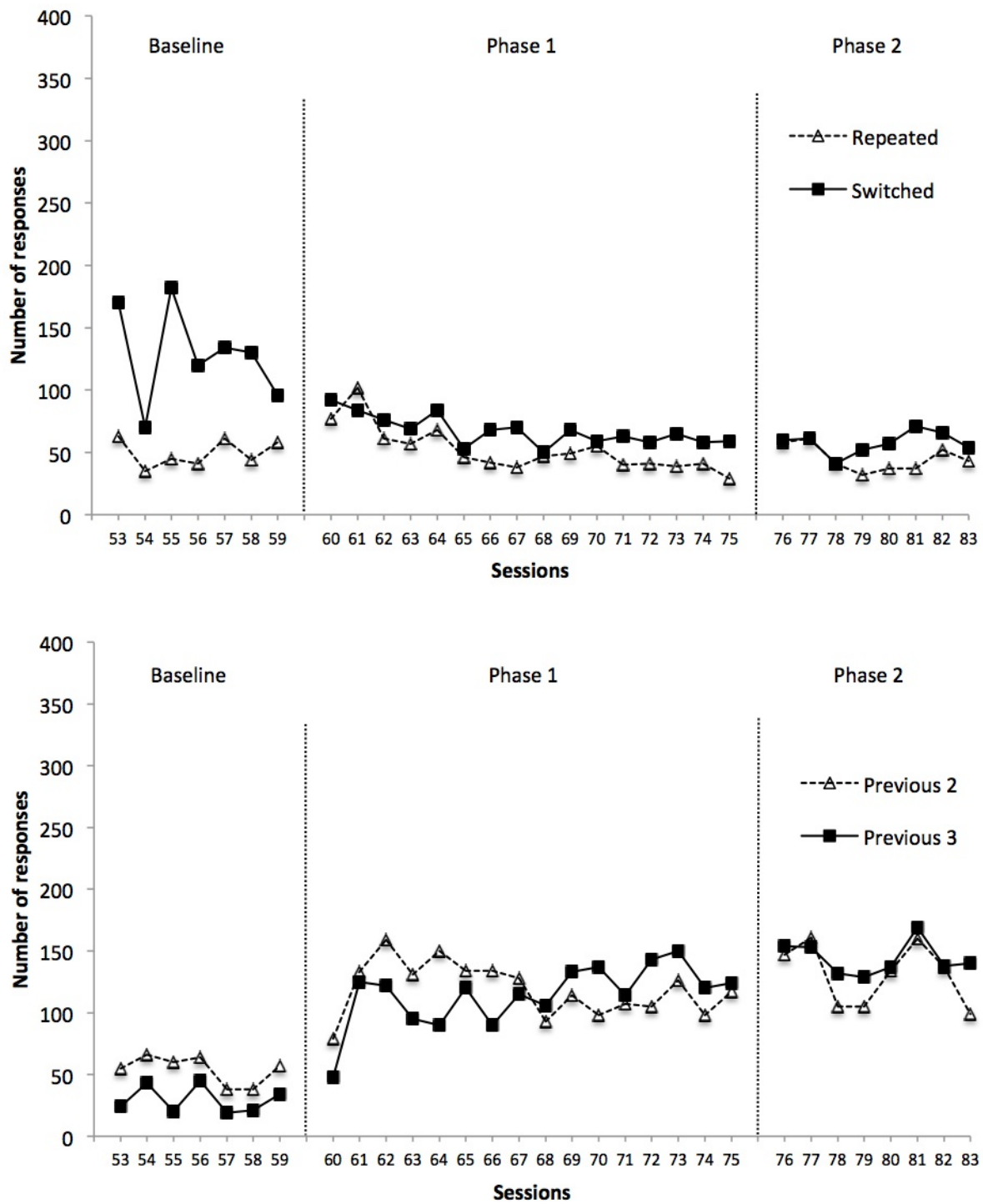
Figure 4. Variability data presented graphically for subject 3985 WKY (Holth-Neuringer). The upper graph displays number of responses per session of repeated (one operandum activated) and switched (two operanda activated). The lower graph displays number of responses of previous 2 (three operanda activated) and previous 3 (four operanda activated). Phase 1 was a Lag 3 Holth-schedule with the criterion of *all* other three operanda visited; Phase 2 was a Lag 3 Neuringer-schedule with the criterion of *any* other operandum visited three times.
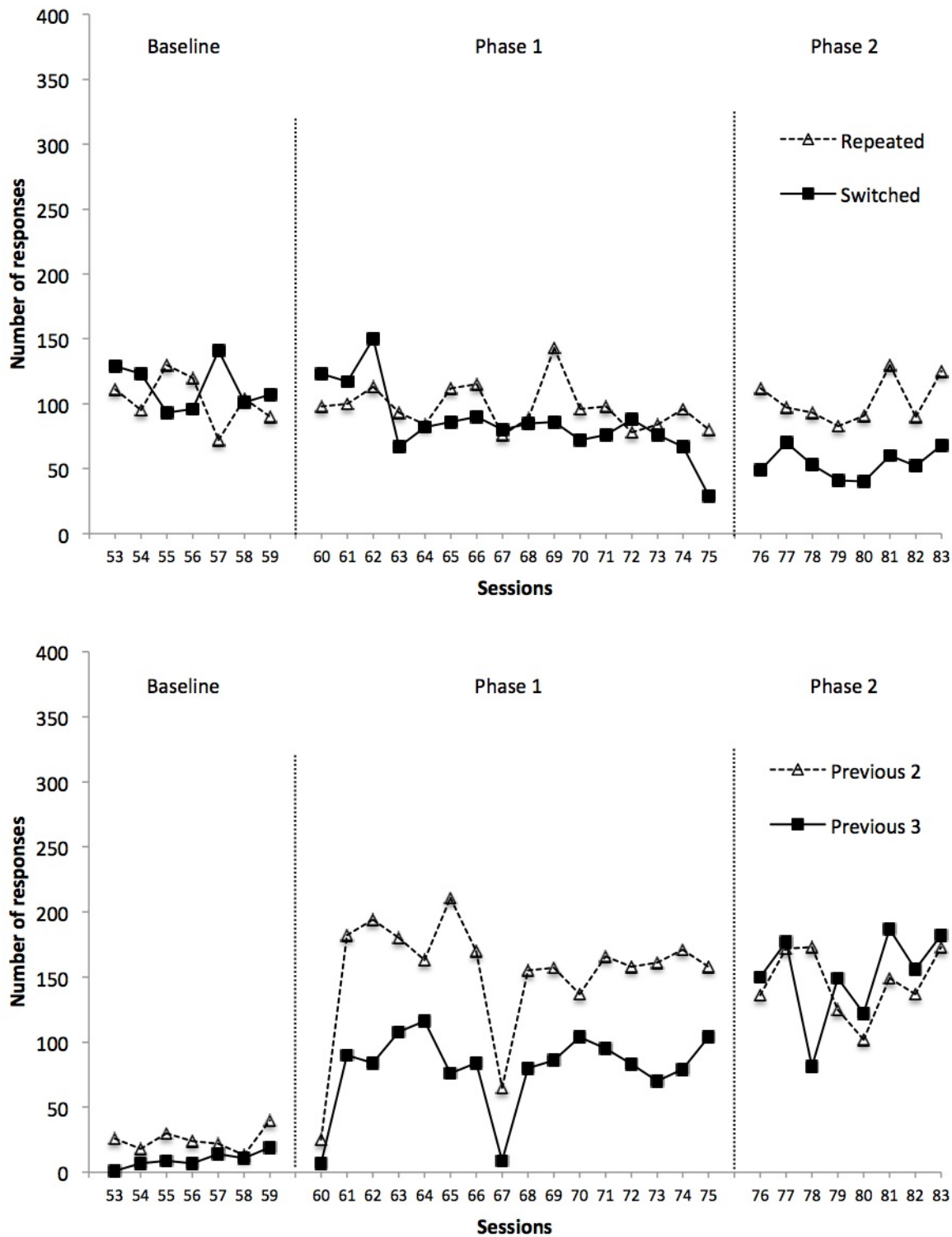
Figure 5. Variability data presented graphically for subject 3986 WKY (Neuringer-Holth). The upper graph displays number of responses per session of repeated (one operandum activated) and switched (two operanda activated). The lower graph displays number of responses of previous 2 (three operanda activated) and previous 3 (four operanda activated). Phase 1 was a Lag 3 Neuringer-schedule with the criterion of any other operandum visited three times; Phase 2 was a Lag 3 Holth-schedule with the criterion of all other three operanda visited.
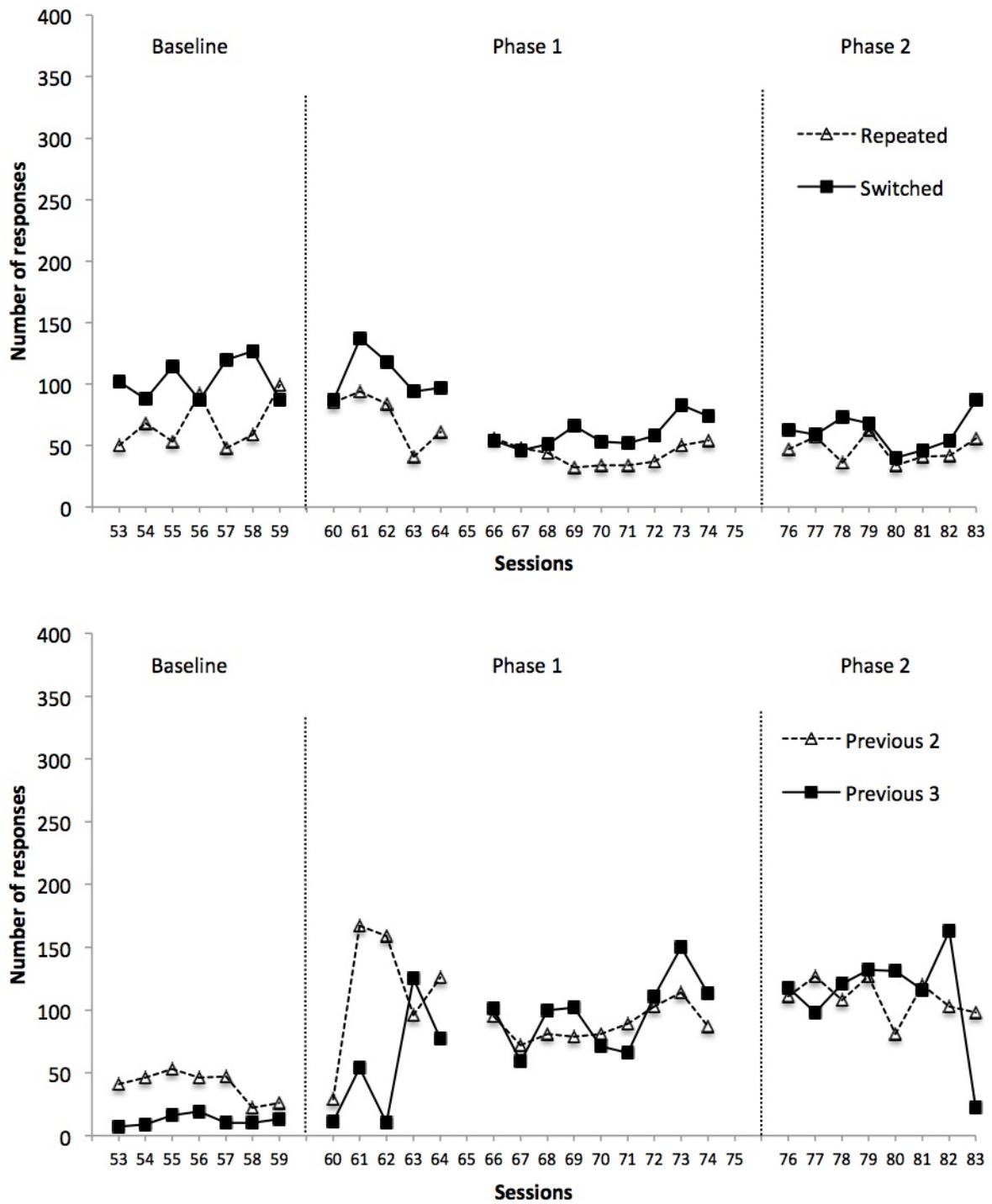
Figure 6. Variability data presented graphically for subject 3987 SHR (Neuringer-Holth). The upper graph displays number of responses per session of repeated (one operandum activated) and switched (two operanda activated). The lower graph displays number of responses of previous 2 (three operanda activated) and previous 3 (four operanda activated). Phase 1 was a Lag 3 Neuringer-schedule with the criterion of any other operandum visited three times; Phase 2 was a Lag 3 Holth-schedule with the criterion of all other three operanda visited.

Figure 7. Variability data presented graphically for subject 3988 WKY (Neuringer-Holth). The upper graph displays number of responses per session of repeated (one operandum activated) and switched (two operanda activated). The lower graph displays number of responses of previous 2 (three operanda activated) and previous 3 (four operanda activated). Phase 1 was a Lag 3 Neuringer-schedule with the criterion of any other operandum visited three times; Phase 2 was a Lag 3 Holth-schedule with the criterion of all other three operanda visited.
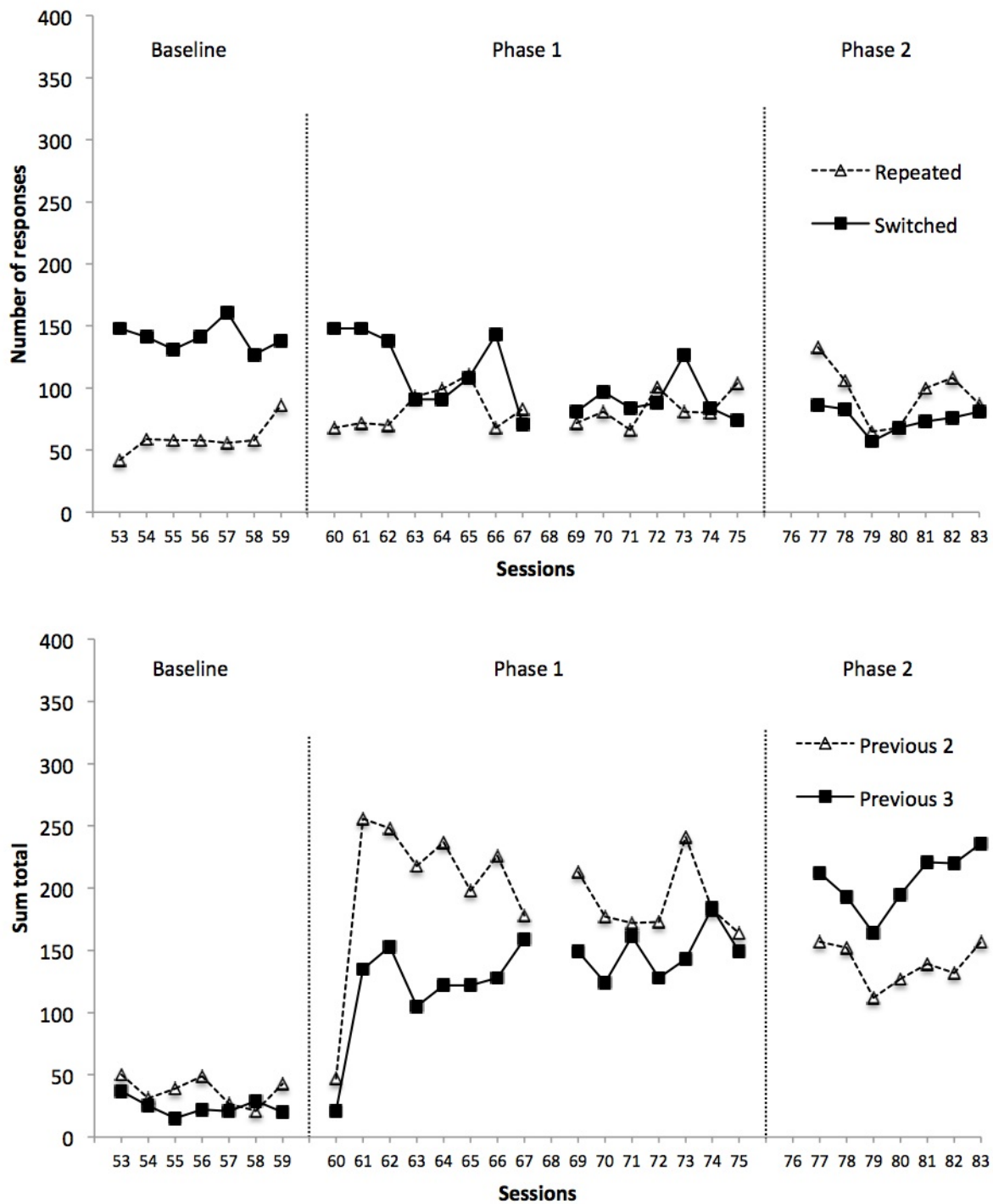
Figure 8. Variability data presented graphically for subject 3989 SHR (Neuringer-Holth). The upper graph displays number of responses per session of repeated (one operandum activated) and switched (two operanda activated). The lower graph displays number of responses of previous 2 (three operanda activated) and previous 3 (four operanda activated). Phase 1 was a Lag 3 Neuringer-schedule with the criterion of any other operandum visited three times; Phase 2 was a Lag 3 Holth-schedule with the criterion of all other three operanda visited.
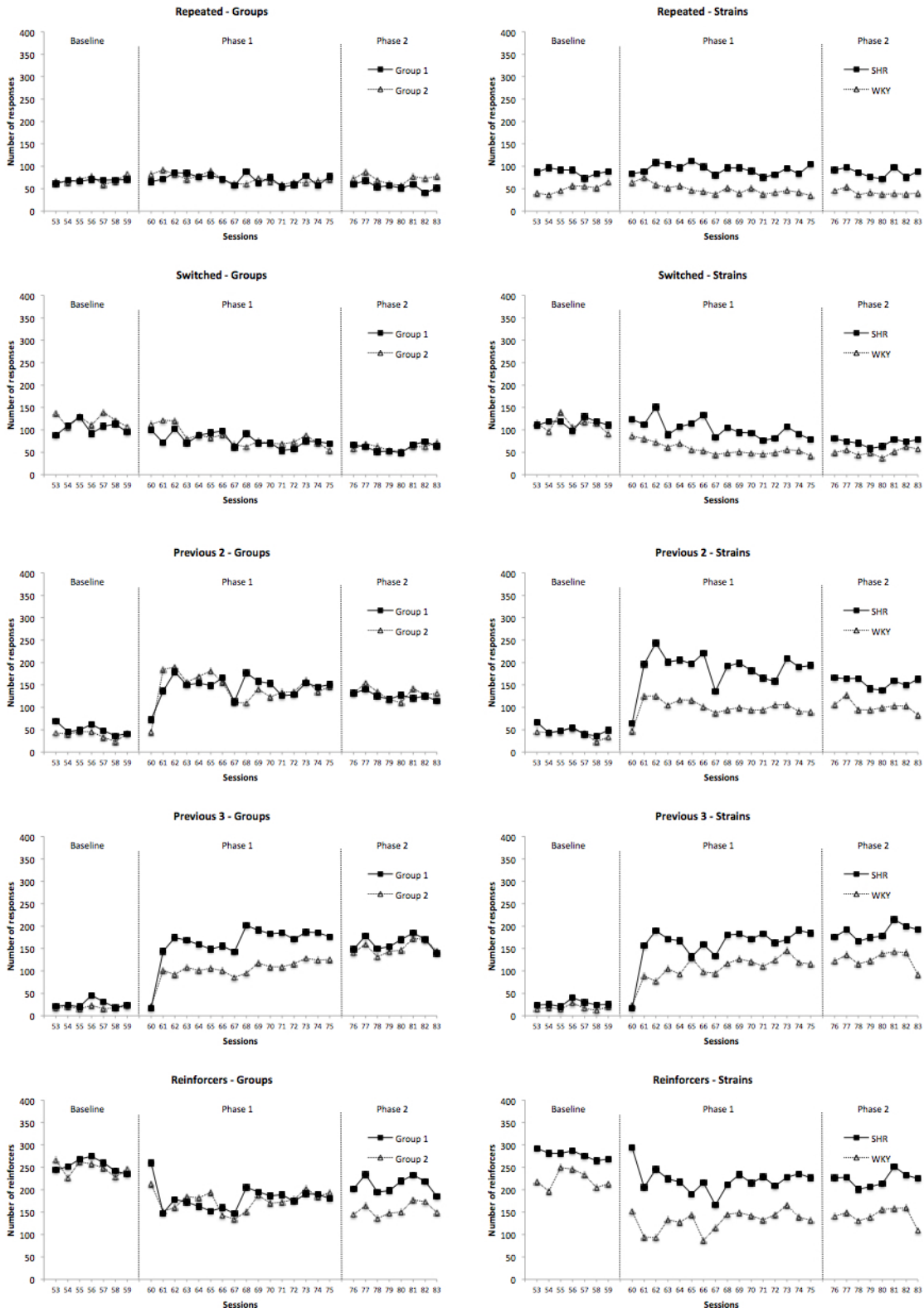
Figure 9. Average data on variability and reinforcers in groups and strains. Left column displays group differences; right column displays strain differences. Group 1 was exposed to Lag 3 Holth-schedule in Phase 1, switching to Lag 3 Neuringer-schedule in Phase 2. Group 2 was exposed to the schedules in the reversed order. The upper two graphs display number of responses per session of repeated (one operandum activated). The graphs in the second row display switched (two operanda). The graphs in the third row display number of responses of previous 2 (three operanda) and the graphs in the fourth row, previous 3 (four operanda). The graphs in the bottom row display number of reinforcers obtained.