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# Etude de la Variabilité Comportementale Chez l'Humain

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Fabricando fit faber, age quod agis.

A mon grand-père et à mon arrière-grand-mère…

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# *Résumé*

Etudier la variabilité comme variable pertinente pour comprendre le changement des comportements humains, tel a été le fil d'Ariane de cette thèse. Il existe en psychologie un large champ d'investigations, chacun d'eux offrant différentes perspectives pour appréhender le comportement humain. La pluralité de ces champs théoriques a une grande influence sur la manière dont certains concepts sont traités, la variabilité est un exemple du fruit de ces différences. En effet la variabilité a, durant des décennies, fait l'objet de nombreux débats : variable parasite ou variable pertinente pour étudier le comportement ? Si l'approche traditionnelle, étant donné ses conceptions théoriques, opte fréquemment pour la première option. D'autres approches, qu'elles soient issues de l'analyse du comportement ou encore des approches dynamiques considèrent les variations comme une variable qui, si elle n'est pas toujours dépendante, peut être manipulée. Durant cette thèse nous avons adopté une approche comportementale, issue des perspectives sélectionnistes qui propose d'étudier le comportement par le biais des contingences environnementales. Elle s'appuie sur l'idée selon laquelle les variations comportementales peuvent être considérées comme une dimension contrôlable par ses antécédents et conséquences. En adoptant cette perspective, nous proposons ici d'étudier l'effet des contingences de renforcement sur la variabilité comportementale chez l'humain. Pour ce faire nous avons proposé deux axes d'études : le premier portant sur la variabilité comportementale et la résistance aux changements, et le deuxième sur le rôle de la variabilité comportementale dans l'apprentissage de comportements émis à une faible probabilité.

Le premier axe comprend deux expériences ayant pour but d'étudier la variabilité comportementale à travers le phénomène de résistance aux changements. Certaines études chez l'animal ont montré que lorsque l'on perturbe l'environnement, la variabilité comportementale est plus résistante aux changements que d'autres patterns comportementaux. Ce premier axe nous a permis de rendre compte des difficultés d'étudier un tel concept chez l'humain mais aussi de trouver des résultats identiques à la littérature animale. Le deuxième axe a eu pour objectif d'analyser l'implication des variations comportementales dans l'apprentissage de comportements apparaissant à une faible fréquence. Cet axe comprend une étude principale ainsi qu'une expérience pilote.

Ces deux axes nous ont permis de montrer, dans la lignée des études chez l'animal, que la variabilité comportementale peut être altérée par des facteurs environnementaux et qu'elle peut jouer un rôle facilitateur dans l'Apprentissage. Ces observations nous donnent l'opportunité d'appréhender les variations comportementales sous un angle différent et peut nous permettre d'avoir une meilleure compréhension de processus d'apprentissage, de créativité, de résolution de problème, aussi bien chez l'animal que chez l'humain.

# *Summary*

This thesis aims at investigating behavioral variations as an important variable to study behavioral changes in Humans. Variability has been let apart in traditional psychology for several years. This situation is directly related to the different ways to encompass and define behavior in psychology. One important part of this thesis has been dedicated to underline the influence and the importance of these different perspectives on the study of behavior. In fact, the place of studies on behavioral variability in research can be considered as an illustration of these different perspectives.

Our investigations have focused on two perspectives to introduce the place of behavioral variations in psychology: essentialism and functionalism. On the one hand essentialism defines behaviors according to their topographies, on the other hand functionalism focuses on the interaction between the environment and behaviors. Despite the common question and because of the differences on the research subject, behavioral variability is differently handled according to the paradigm of research. Indeed, from an essentialist perspective, behavioral variation is considered as a confounding variable which has logically been let apart. From a functionalist perspective, more precisely in selectionism, behavioral variability takes an important place in behavioral selection. We adopted in our works a functionalist perspective in which behavioral variability is considered to be the result of environmental changes. Moreover, it shows that controlled variations can be implied on several aspects of behavioral changes. However, this thesis consists of experimental studies investigating behavioral variability in humans. Our experimental works can be divided into two parts:

First, we investigated how environmental changes affect the persistence of variable behaviors. Studies with animals have shown that despite environmental disruptors, behavioral variability is more persistent to change than other behavioral patterns. These first studies aimed to investigate behavioral variability and to understand the mechanism which might affect it.

The second part of our experimental investigations dealt with the relation between behavioral variability and the acquisition of less probable behaviors. It can be divided into two experiments First, Inspired by previous works with humans and animals, we carried out an experiment which demonstrates that behavioral variability facilitates the acquisition of less

probable sequences. The second experiment can be considered as a pilot study in which we investigated how variable responses can be transferred to other modalities.

# Investigation of Behavioral Variability in Human

# 1. Chapter 1: Theoretical Introduction

In the first part of this introduction, we present the theoretical context which defines variability in psychology. Debates on behavioral variability are the result of a long history and different ways to study behaviors. We will present two main perspectives: traditional perspective influenced by an essentialist approach and behavioral perspective influenced by a selectionist approach.

In the second part, we will introduce how these two conceptions of psychology have affected the way behavioral variability is examined. Once the foundation established by the historical context, we will adopt a behavioral perspective to study behavioral variability and emphasize its importance in behavioral changes. In fact, from a selectionist perspective, behavioral variations are the basis upon which selection of behaviors is possible. Investigation on behavioral variability may contribute to a better understanding of learning processes in many species.

The last part of this introduction focuses on the different methodologies used to investigate behavioral variability from a selectionist perspective. Considering that behavioral variability might be controlled by environmental contingencies, experiments have shown that behavioral variability can be controlled by its antecedent and consequences with many species. Second, we have investigated the relation between behavioral variations and the acquisition of rare responses. Results with animals suggest that reinforced variability enable the selection of rare responses but results with human are more disparate.

## 1.1 The Study of Human Behavior in Psychology: Epistemological Context

For longtime, psychology has been considered as the science of mind and behavior. This definition is influenced by an essentialist perspective (Palmer & Donahoe, 1992; Donahoe, Burgos & Palmer, 1993; Donahoe, 2012).The word "Essentialism" was introduced by Karl Popper (1945). It assumes that observable objects are characterized by their essence, an underlying immutable cause of what makes an object what it is (Popper, 1945; Mayr, 1988).

> *"Essentialism is the view that certain categories have an underlying reality or true nature that one cannot observe directly but that gives an object its identity, and is responsible for other similarities that category members share. In the domain of biology, an essence would be whatever quality remains unchanging as an organism grows, reproduces, and undergoes morphological transformations (baby to man; caterpillar to butterfly). In the domain of chemistry, an essence would be whatever quality remains unchanging as a substance changes shape, size, or state (from solid to liquid to gas)". (Gelman, 2004)*

The essentialist perspective was predominant in most of human and natural sciences until the 19th century. In 1859, with the publication of *The Origin of Species*, Darwin proposed a theory which acted as a counterbalance to the dominant position of essentialism. He provided two ideas that revolutionized the scientific area. First, the principles of Evolution which can be defined as change in the characteristics of biological population over successive generation (Hall & Hallgrimsson, 2011). In Evolution Theory, changes, which were considered to be anecdotal in the essentialist perspective, because essence is immutable, became the variables under investigation. The second idea is that Evolution is made through a process labelled "natural selection" which is responsible for changes Animal just as Human characteristics.

Natural selection consists of three principles: variation, selection and retention. Variation refers to the different characteristics between organisms providing a basis upon which selection is possible. Applied to Human being, these variations refer to the different characteristics (color, length etc.) which are observable (or not) between two individuals of the

Human species. Environment directly affects substrates of variation, making some characteristics essential to survive or on the contrary, making others useless. Considering our example, selection process has directly influenced the functional differences between individuals, for instance, we can observe structural and functional differences between an individual living in North Pole and one living in Amazonia. This second principle is defined as selection. Selection is not described as a goal-oriented process. Mutation of organisms are the result of many processes combined and do not serve a purpose. Changes in environment might favor or disfavor the features of some organisms. Finally, the last step of natural selection, named hereditary selection, or retention, consists in enabling the selected characteristics to be transmitted to the offspring. Natural selection as a process to explain evolution offered new perspectives to investigate human and natural sciences.

Three aspects of selection process can be emphasized and put in contrast with essentialism perspective. First, natural selection is based on the interdependence of variations, selection and retention. This process can be observed and contribute to an explanation of change. Second, for Darwin, natural selection is the result of the interaction between substrates of variation and environmental contingencies. An implication of this interaction is that organisms are not responsible for selection — interaction is. Natural selection introduced the concept of function, which is the idea that the lifespan of species is directly dependent to their interactions with Environment. The concept of function can be put in contrast with the idea of structure in essentialism. Indeed, the structure or form of organisms is privileged because it enables classification. In psychology, different structure (i.e. internal variables) are responsible for different class of behaviors. Otherwise, function as the action of an organism on the environment is preferred in natural selection. In this context, behaviors are not classified depending on their structure but on their effects on the environment. Lastly, even if Darwin did not mention it in his book, he produced a theory which can be applied to all species, from cells to human beings. From then on, human beings are not considered to be on one side, but are submitted to the same natural laws as other species. This perspective can be considered as a starting point for the scientific comparison of “human animals” and “non-human animals” (Charlesworth, 1992). At this time, natural selection has been largely adopted in science community. In biology, selectionism was rather quickly accepted despite the essentialist and teleological reluctance (Palmer & Donahoe, 1992). In psychology, based on an essentialist perspectives, research investigated mind. Because of this epistemological context, selectionism

tended to be less accepted than in natural sciences. However, at the end of the 19th century, some authors contributed to the rise of a selectionist approach in psychology (Pavlov, 1927; Thorndike, 1898, 1911; Watson, 1913; Skinner, 1957).

In psychology, researchers influenced by a selectionist perspective have investigated the interaction between behaviors and environment. Thorndike (1911) was one of the first psychologist who studied these interactions by investigating the effects of consequences that follows behaviors. Learning is a term which can be associated with behavioral changes. Considering learning as a situation in which behaviors are affected by their consequences, he investigated success and failure that follow behaviors. He named that changes: trial and error learning. In a series of experiments Thorndike created a "puzzle box": which consisted of box with a system of door locked. In these experiments Animals were locked in the box and food were outside, to obtain food animals had to "figure out" how to open the door (see figure 1).

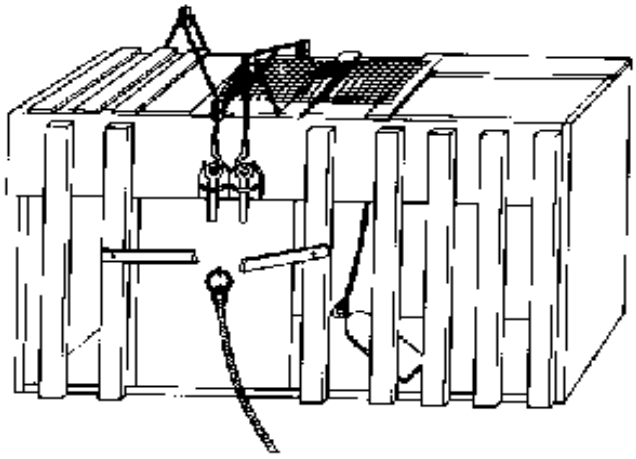


FIGURE 2.9 Thorndike's puzzle box. (Thorndike, 1911)

**Figure 1:** Thorndike's puzzle box (Thorndike, 1911)

Thorndike observed that animals emitted many responses in the box, only some of them resulted in opening the door and then give access to food. Most of animals took less and less time to open the door after they repeatedly returned to the box. Based on these results, Thorndike formulated the law effect stating that behaviors are affected with the consequences that follow them. Interestingly, we can notice that, Thorndike, in the traditional influence essentialist perspective investigated Intelligence, defined in this context as the ability to solve

a given problem (e.g get out of a locked box). Behaviors emitted to resolve problems were considering to be the expression of animal intelligence. Otherwise, from a selectionist perspective, responses emitted by the animals, were the result of their interaction with consequences. This conception of interaction between behavior and environment paved the way to modern behaviorism. Responses emitted in the puzzle box which were different from each other refer to the concept of variability. In that situations we can presumably emit at least two hypotheses. The question is how animals succeeded in opening the locked door. In other word, how problem solving works? Considering that animals emitted many responses before the opening of the door, first, based on an essentialist perspective, these responses are the result of an internal variable. In that case, they could just inform us about Intelligence. Second, based on a selectionist perspective, we can assume that the interaction between these variable responses and environment led to the selection of target response. In that case, investigating these variation may inform us in the acquisition of problem solving.

### 1.1.1 Behavioral Variability in Psychology

Behavioral variability commonly refers to the degrees of change that occur at different moments and spaces (Neuringer, 2002; Van Geert & Van Dijk, 2002). These variations can be investigated in a continuum between repetition, which implies prediction, and variation, which implies unpredictability. Commonly, experimental psychology is about description, prediction and control. One experimental question is: *To what extent is a change in a dependent variable the result of the manipulation of independent variables?* In classic textbooks on psychology, variability is described as an impediment to experimental conclusions. Indeed, it prevents the conclusion of the influence of the independent variable on the dependent variable when conditions are held constant. In an experiment, we study the influence of a variable A on a variable B in a repeated measured design. The basic and possibly the most common hypothesis is that B co-varies with A (see figure 2 for an illustration of variability in experimentation). If, when we verify this hypothesis, changes in A are independent of B, prediction is impossible. In this case, internal validity can be questioned. This situation has been an issue for many scientists independently of their theoretical backgrounds. In fact, the difference is in the way to handle variations in data. From a traditional perspective these variations are confounding variables which cannot be controlled. From a functional perspective, variability can also be a problem except that theoretically, it can be influenced by environmental contingencies. Moreover, this

variability, from a selectionnist perspective can be a basis upon which selection is possible. In Thorndike's experiments (1911) animals emitted different responses to get out of the puzzle box. We can imagine that, if they emitted no response, there is low probability in their success. In fact, one hypothesis is that, among the different responses emitted by the animal, some was selected by the opening of the door. The more the animal returned to the box, the more probable it emitted the correct response to get out. In that case, behavioral variability can also be a variable inherent to the trial and error learning. The next section aims at presenting the influence of the different conceptions on the way to consider variations.

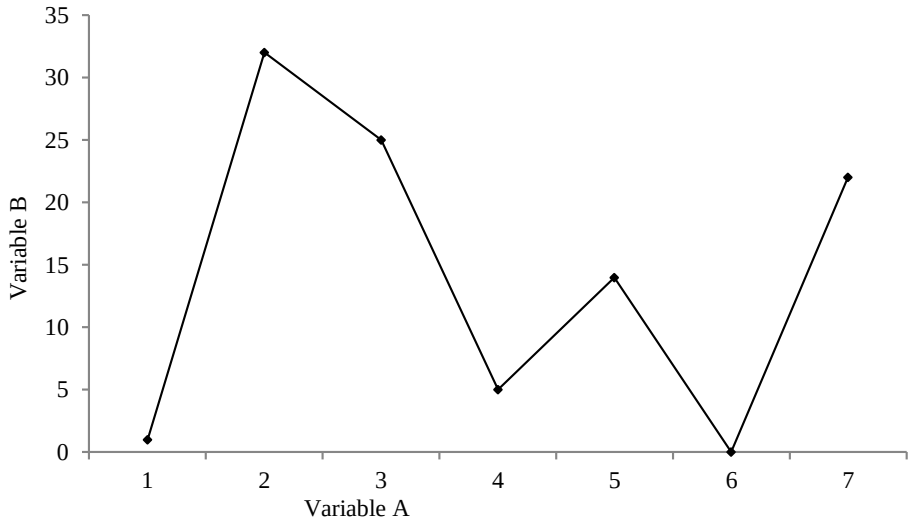



**Figure 2.** Instance of variability in an experiment

## 1.1.2 Behavioral Variability in Traditional Psychology: A Confounding Variable?

As previously described, traditional psychology assumes the existence of an internal variable which would be responsible for human behaviors. It is important to emphasize that in this case behaviors are considered to be means to reach the internal variable, which is the actual variable under investigation. For instance, in Thorndike's experiment, investigating how long animals took to get out of the box informs on the degree of Intelligence. Using mainly hypothetico-deductive methods, researchers design experiments in which they observe the influence of a given variable on behaviors and then conclude the effect on an internal variable. The main consequence of this methodology is that a number of studies in psychology emphasize

the correlations between events more than the functional relation, in the same time, to investigate the target internal variable, experimenters use between subjects designs (Van Geert & Van Dijk, 2002). These designs analyze the performances trough correlations and differences in central tendency between subjects.

Let us take the example of a concept which is commonly investigated in psychology: the case of memory. As quoted by Sternberg (1999): "Memory is the means by which we draw on our past experiences in order to use this information in the present". One typical experiment consists in presenting stimuli to a subject (e.g. letters, numbers, words etc…), and secondly to ask him to re-establish them. Experimenters can manipulate the time of restoration, the position of the stimulus or topography etc. (Peterson & Peterson, 1959; Atkinson & Shiffrin, 1968). In these experiments, researchers assume that the behavior "to re-establish the stimulus presented" is the expression of memory. However, in the same experiment and even when conditions are held constant, depending on the analysis design we can observe two types of variations. First, intra-individual variability, which consists of fluctuations in the performance of a given subject for the same conditions. For instance, one subject might have different performances for the same experiment. Second, performance might be different between subjects in the same conditions, which refers to inter-individual variations. Intra-individual and between-subject variability, changes in performances independent to the researcher manipulation have been considered problematic in Science in general. However, when we look at intra-individual variations, changes in performance of a subject in an experiment. Independently of the perspective taken it is usually synonym of absence of control.

Because of the influences of essentialism, most psychologists assume that variability is also an internal variable—like memory for instance (Lautrey, 2003). Moreover, it is considered to be randomly assigned in any given situation. In experimental contexts, variability is considered to be the outcome of two sources. On the one hand, variability is the result of the situation. That is, researchers consider that different situations may induce differences in individual performances. In our example, experimentations could be done in different settings (which were not controlled). In order to reduce this variability, researchers have set up standardized situations. The latter aims at creating a consistent environment to enable the study of the internal variable and to reduce noise. On the other hand, in traditional psychology, a second source of variability is related to error measurement. This hypothesis is illustrated in the

true score theories which assume that a behavior can be divided into two parts: on the one hand, the true score, which is the exact reflection of the intrinsic variable under investigation; on the other hand, the error measurement error, which is the difference between observed behavior and "true" skills (Lautrey, 2003).

This way of considering variability reveals the influence of the essentialist perspective. In fact, variability is considered to be inaccessible, and therefore parasites the expression of the variable under investigation (Schlinger, 2013). This analysis may contribute by explaining why researchers focus on smoothed trajectories**.** One common way to deal with variability in psychology is to use statistics in order to extract reliable data (Van Geert& Van Dijk, 2002). Statistics enable to control or cancel out the random nature of variability in experiment. It is a tool which is widespread in psychological literature.

> *People are complicated, and it is hard to find principles of human behavior. Consequently, psychological research is often difficult and frustrating, and the frustration can lead to a flight into statistics. With some, this takes the form of a preoccupation with statistics to the point of divorcement from the headaches of empirical study […]. Psychology had a proud beginning, and it would be a pity to see it settle for the meager efforts which are encouraged by the use of the hypothesis-testing models. The original purpose was to find lawful relations in human behavior. We should not feel proud when we see the psychologist smile and say: "the correlation is significant beyond the .01 level»; perhaps that is the most that he can say, but he has no reason to smile. (Nunnally, 1960)*

This way to investigate human change has been questioned and several authors have warned against the abusive use of statistics, considering that it might lead to an information loss (Loftus, 1996)**.** However, if variability can be an impediment to experimental control independently of the perspective taken, we can either consider it as an uncontrolled variable. In this case, this dissertation would finish here. Otherwise we can consider variations as the object of environmental contingencies. The latter implies that it is possible to control it. The aim of this introduction was to emphasize how far different theoretical conceptions lead to great discrepancies in the same field and despite the same apparent goal. Here, the concept of

variability is analyzed in completely different ways depending on the perspective taken. The next section presents variability from a functional perspective.

### 1.1.3 Behavioral Variability in Functional Perspectives

Functional perspectives are direct successors of Darwin's work. These perspectives investigate the relation between behaviors and environmental contingencies using mostly single subject design. There are not interested in the performance of a group but individual. They assume that behavior is directly dependent on environmental changes—and vice versa. The publication of *Psychology as The Behaviorist Views it* (Watson, 1913) emphasized the will to create a science of behavior:

> *I do not wish unduly to criticize psychology. It has failed signally, I believe, during the fifty-odd years of its existence as an experimental discipline to make its place in the world as an undisputed natural science. Psychology, as it is generally thought of, has something esoteric in its methods. If you fail to reproduce my findings, it is not due to some fault in your apparatus or in the control of your stimulus, but it is due to the fact that your introspection is untrained. The attack is made upon the observer and not upon the experimental setting. In physics and in chemistry the attack is made upon the experimental conditions. The apparatus was not sensitive enough; impure chemicals were used, etc. In these sciences a better technique will give reproducible results. Psychology is otherwise. If you can't observe 3-9 states of clearness in attention, your introspection is poor. If, on the other hand, a feeling seems reasonably clear to you, your introspection is again faulty. You are seeing too much. Feelings are never clear. (Watson, 1913)*

According to Watson, psychology needs to be considered as a natural science in the same way as physics and chemistry. It must study human and animal behaviors objectively and experimentally (Watson, 1913). This may be the most important difference between essentialism and functionalism: the variable under investigation. On the one hand, behaviors are just a means to reach the real variable investigated, and on the other hand, behaviors are considered to be the only variable which has to be investigated to understand human change.

In the continuity, Skinner proposed a descriptive science based on functional relation between organism behavior and environment. In his article "Are theories of learning necessary?" (Skinner, 1950), he proposed to break away from hypothetico-deductive methods. Actually, he assumed that many theories in psychology are based on phenomena which are not directly observable. These phenomena are internal constructions which are the bases to explain behavior. According to Skinner, this way to investigate behavior based on hypothetico-deductive method is detrimental to a scientific explanation. Skinner proposed different means to investigate behavior in a standardized way — behavior analysis was born. The field aimed at looking at the environment and finding determinants of behavior that did not have apparent antecedent cause (Donahoe, 1996). Inspired with Darwin's works, the functional relation between behavior and its environmental determinant is the core of behavior analysis. In the book *The Behavior of Organisms* (1938), Skinner described how behavior analysis investigates this relation. Behaviors can be analyzed from two types of conditioning: classical and operant conditionings. In classical conditioning, respondent behavior, first analyzed by Ivan Pavlov (1927), refers to behaviors which are elicited by stimuli that immediately precede them. These behaviors are considered to be involuntary which means that they are emitted whenever the preceding stimulus is presented. Operant behaviors are not elicited by antecedent stimulus but change depending on stimulus changes that have followed the behavior in the past. From a traditional perspective, these behaviors are considered to be voluntary action which are emitted without apparent reason. Operant behaviors can be analyzed through a three-term contingency, the basic unit of analysis in the study of behavior—avoiding hypothetical construct. Functional perspective investigates Human behavior using single-subject design which consists of experiment in which subject serves as his own control (Sidman, 1960).

The three-term contingency describes the temporal and possibly dependent relations among an antecedent stimulus, behavior and consequence. To explain the apparition of a given behavior, behavior analysts describe the antecedent and the consequence. The antecedent is the environmental stimulus change occurring prior to a behavior. The consequence is any change which occur immediately after a behavior. The operant behavior is the basic unit in behavior analysis. An operant behavior is controlled by its antecedent and its consequences. According to Skinner (1938), an operant relation is the process by which a response produces environmental changes which in return alter this response. The relation between responses and environmental contingencies is the core of behavior analysis. In fact, by systematically

manipulating stimulus that preceded and followed behaviors, behavior analysis has revolutionized the study of behavior.

> *Control is another matter. Avoiding mentalism (or "psychologism") by refusing to look at causes exacts its price. Structuralism and developmentalism do not tell us why customs are followed, why people vote as they do or display attitudes or traits of character, or why different languages have common features. Time or age cannot be manipulated; we can only wait for a person or a culture to pass through a developmental period. (Skinner, pp 217, 1974)*

Based on Darwin's *On the Origin of Species,* the behavioral perspective offers to consider complex phenomena as a cumulative product of simple processes acting over time (Donahoe, 2012). Behavioral variation and selection by consequence are two important processes in behavioral changes; hence without variations the selection of new behaviors is not possible. The analogy described by Skinner (1981) between behavioral perspective and natural selection is an important starting point to understand the role of variability in behavioral changes. In natural selection, without substrate of variation and without environmental constraint, species do not change. It seems that the same relation between behavior and the environment may explain behavioral changes. Actually, the behavioral perspective considers the complexity of behavioral changes as the result of the interaction between organism behavior and its antecedent and consequences. The likelihood of a response increases or decreases according to the immediate change which follows it. For behavior analysis, selection by consequences differentially selects behaviors that are followed by certain consequences. Skinner (1981) presented three levels of selection by consequences: natural selection, selection by operant conditioning and cultural selection. Natural selection provides inherited responses (e.g. respondent responses) that enable the survival of the organism. From this legacy, operant conditioning is the process which selects new behaviors from the previous substrate. It implies the relation between the probability to emit a behavior and the probability of the apparition of a stimulus. Lastly, cultural selection refers to behavioral selection by transmission from one individual to another (Catania, 2017). Behavioral analysis is based on two fundamental units, response and stimulus, which are described from a functional point of view. A response is

defined as the action of an organism and a stimulus as an environmental change that modifies an action (Skinner, 1938).

The selectionist analogy can be divided into two parts: behavioral variation, which is the starting point of the second part, selection by consequences (see figure 3). Despite the analogy proposed by Skinner (1981), behavioral variability has been neglected even in the behavioral perspective for several years. Selection by consequences is the area of research which has been the most prolific for the past sixty years (Richelle, 1984; Boulanger, Ingebos, Lahak, Machado, & Richelle, M., 1987). Selection by consequences considers different ways to alter the probability of a behavior occurrence. Mainly three processes have been investigated: reinforcement, punishment and extinction.

- Reinforcement refers to a procedure in which consequences are manipulated in order to maintain or increase the likelihood of a behavior occurrence. These manipulations consist in either adding or removing a stimulus immediately after the emission of a behavior.
- Punishment refers to a procedure in which consequences are manipulated in order to decrease the probability of occurrence of behavior.
- Extinction is a procedure which consists in withdrawing consequences for behaviors that have previously been reinforced. It results first in an increase of behavioral variability and then in a decrease of behavior frequency (Skinner, 1951).

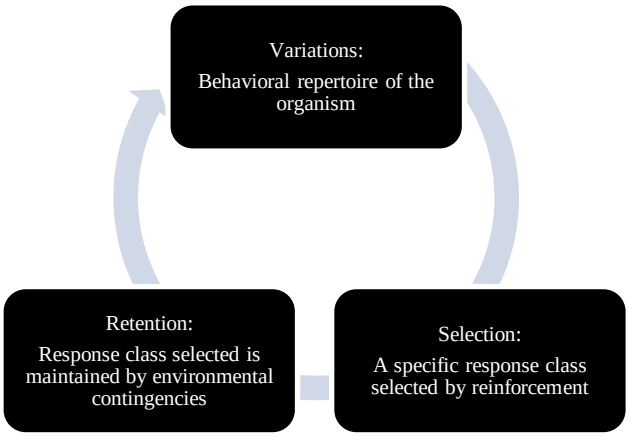



**Figure 3.** Selection by consequences process

Researchers studying selection by consequences generally investigate these three processes (Epstein, 2007; Lerman, Kelley, Vorndran, Kuhn & Larue, 2002). In the 1960s, reinforcement studies were predominant in behavior analysis. In fact, reinforcement drew the line of how behavior can be selected by environmental contingencies. The textbook *Schedule of reinforcement* (Ferster & Skinner, 1957) is an instance of investigation on selection by consequences. In this book, the authors investigated how different schedules of reinforcement affect the organism's responses. A schedule of reinforcement is a specific rule which specifies environmental arrangement and response requirement for reinforcement. Ferster and Skinner described operant responses across different types of dimensions (i.e. repeatability, duration or temporal locus). The dimension of a response is a measurable characteristic of behavior. For instance, repeatability of lever press can be shaped by environmental contingencies. We could reinforce either two occurrences of a response or three etc… Commonly, response patterns are described in terms of stable states.

To illustrate the work of Ferster and Skinner (1957), we can take the example of a Fixed Interval schedule of reinforcement (FI). This schedule consists in reinforcing the first response emitted after a given elapsed interval. For instance, in a FI 1 minute, the first response emitted after one minute is contingently reinforced. Like other schedules of reinforcement, a FI schedule is described across stability patterns. Commonly, FI implies an increasing response rate at the end of each interval. Once reinforcement is distributed, we can observe a period of no responding named post-reinforcement pause. After this pause, the rate of responses positively accelerates up to the delivery of the next reinforcement (Poppen, 1982; Darcheville, Rivière & Wearden, 1992, 1993). These observations are carried out for a specific dimension

of behavior and from a macroscopic point of view. They are described as a steady state pattern. This point of view may be a similarity shared with traditional psychology. Macroscopic description offers the impression of stability, but as pointed out by Skinner, when we look at the data more closely, we can observe variations in different dimensions of responses (see figure 4) (e.g. response rate, post reinforcement pause, duration, etc). These variations are similar to the one we previously described and referring to intra-individual variations.

Regardless of what we do, we must recognize that behavioral variability is inherent to the study of behavior. From a behavioral perspective, these behavioral variations we can observe experimentally or in natural environment are the results of two main interdependent sources. First, because behaviors are subjected to the same laws of physics as any physical event, they are submitted to mechanical and biological constraints which create variability. This variability refers to endogenous variables.

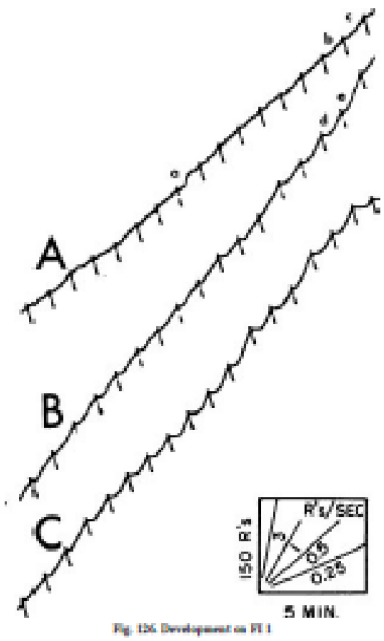



**Figure 4.** Instance of interval reinforcement schedule, From Ferster & Skinner (1957). Dots are reinforcement distribution. The letters A, B, C represent the performances of three different pigeons.

The second source of variability which will be the core of this dissertation is external environmental contingencies. In fact, behavior analysts assume that the variations that we can observe in an experiment can be altered by changing environmental contingencies. This perspective enables us to assume two hypotheses. First, if in an experiment we observe

variability, it can be altered with the manipulation of environmental contingencies. Second, the interaction between variable behaviors and consequences might be in a given context the basis upon which selection is possible. Moreover, considering the theoretical perspective of behavioral approach, variability and selection by consequences must be investigated to understand behavioral changes (Marr, 2012). Considering that these behavioral variations as controlled variable, we will adopt in this thesis a functional perspective.

Theoretically, studying behavioral variability and reinforcement process can be considered as a conundrum. On the one hand, variability is inevitable for response selection, but on the other hand, reinforcement may inevitably lead to response repetition. Indeed, selection by consequences implies the emission of one response among others that will be followed by reinforcement and that have thereafter, by definition, a higher probability of being emitted again in the future—unlike other responses. In this context, one can easily argue that reinforcement decreases variability. In our example of verbal behavior selection, the standard selection of the community tends to select intelligible vocalizations within a pool of sounds emitted by the toddler. So, if reinforcement may induce repeatability of an operant response, understanding how variability can be controlled by environmental contingencies challenges the understanding of behavioral changes. Now, let us examine the relation between variability and operant response more closely.

According to Skinner (1951) an operant response which is selected might vary once it exceeds the minimum criterion of reinforcement. Let us go back to our previous behavioral patterns observed in a FI Schedule of reinforcement (Ferster & Skinner, 1957). An operant behavior can be defined by several dimensions (i.e duration, count, strength etc…). The lever press of a rat in a FI schedule can be analyzed in this way: the behavior can be reinforced only if both duration and strength reach a minimum criterion. Beyond these values, if no other constraints are defined, there is a high probability that force and duration may vary between different trials. The aim of the first experiments on behavioral variability was to study these variations. Research have investigated the effect of schedules of reinforcement on the variability of the operant dimension of behavior.

## 1.2 Experiments on Behavioral Variability

### 1.2.1 Behavioral Variability and Animal Studies

Antonitis (1951) was the first to directly investigate the variability of operant response. Previous experiments (Skinner, 1938; Muenzinger, 1928) observed first that the variability of operant responses decreases in a Continuous Reinforcement Schedule (CRF). This schedule consists in systematically reinforcing each occurrence of a target behavior. For instance, distributing food systematically when a rat presses a lever may decrease the dimensions of variation related to this response (duration, location etc…). In other words, there are variable ways to press a lever and CRF schedule seems to reduce these variations. Second, it has been observed that these variations increased in extinction phase. In our example, when food is no longer distributed when rat presses the lever, it results in an increase of responses variations. The study of Antonitis aimed at assessing the relation between CRF – which seemed to reduce variability – and extinction – which induces variability. In his experiment, rats were reinforced when they poked their nose on a 50 cm horizontal slot without any constraint of location. The experiment alternated between CRF and extinction phases. During the CRF phase, the poked area, was high at the beginning of the experiment, which implies that rats tended to use the 50 cm surface of the horizontal slot. This area became restricted to a smaller region despite the absence of constraint, suggesting that CRF results in reducing variations. Repeating the same type of response over trials is categorized as stereotyped behavior. On the continuum of behavioral variability, it consists of repetitive pattern of behaviors. Although the CRF phase produced stereotyped pattern of behaviors, once under extinction, the poked area became more variable. Evidence of variability in this experiment was investigated by assessing the area of the poked location. The results of this experiment were replicated in several studies and across different operant responses (Tremont, 1984; Milenson, Hurwitz & Nixon, 1961). Overall, these experiments shown that CRF induces stereotyped behaviors but that extinction induces both a decrease of response rate and an increase in operant variability.

In order to investigate how environmental contingencies affect the continuum between repetitive and variable behaviors, researchers probed the effect of intermittent reinforcement. This schedule of reinforcement consists in reinforcing some but not all occurrences of behaviors (Schlinger, 2008). For instance, in a Variable Ratio schedule 5 (VR 5), reinforcement is

delivered on an average of 5 responses. The main hypothesis with this type of schedule is that intermittent reinforcement can be viewed as a series of extinction and reinforcement phases (Schoenfeld & Cole, 1975). Data suggest that the use of intermittent reinforcement after a CRF schedule may induce a certain degree of variability of the operant response. Tremont (1984) carried out an experiment in which rats were intermittently reinforced in pressing a bar. He measured the degree of variability of Inter-Response-Time (IRT). The author found that variations in the IRT was related to the level of intermittence. In other word, more disparate was reinforcement, more variable was the IRT. These experiments have provided new information on variability. First, it is directly related to the reinforcement contingency which may favor the assumption that variability can be influenced by environmental contingencies. Second, the reversible aspect of variability may be a first step to control it. However, the simple aspect of these responses (e.g. nose poke, lever press) was considered as a limitation to generalization. Indeed, these types of responses are distant from the complex responses emitted with humans. In this dissertation, complexity of response will be based on Palmer and Donahoe's (1992) definition which is: "complex response can be considered as the superimposition of simple responses." According to Palmer and Donahoe (1992), complexity can be analyzed with multiple simple unit of response. In that definition, complex and simple responses are supposed to be submitted to the same law of conditioning.

In order to investigate variability with more complex responses, researchers have created an apparatus in which animals have to emit sequences of responses instead of a single one. In order to investigate the variability dimension of complex responses, Vogel and Annau (1973) created an apparatus consisting of a 4x4 matrix of stimulus lights, two response keys, left key (L), right key (R), and a feeder light. Pigeons had to peck on two keys in order to move a stimulus light on the top left position to the bottom right position of the matrix. Figure 5 illustrates the apparatus of this experiment. A peck on one key moved the light to the right, pecking the other key moved the light to the bottom. Reinforcement was distributed when pigeons emitted a sequence of three pecks on each key which resulted in the move of the stimulus light on the bottom right position of the panel. A 2s time-out was contingent on a fourth response. The results of the experiment are the same as the previous simpler operant responses. At the beginning of the experiment, pigeons emitted variable behaviors, and then emitted more stereotyped behaviors. The same outcome was found with other studies (e.g. Pisacreta, 1982) using an identical apparatus. Most experiments investigating the variability of

operant responses under a CRF schedule and extinction report the same type of data. First, it has been shown that a CRF schedule induces stereotyped behavior. In other words, without constraint, a continuously reinforced behavior tends to be repetitive (Pear, 1985; Boulanger, Ingebos, Lahak, Machado, & Richelle, 1987). Reducing variability implies that specific responses from a response class can be selected. It may confirm that from a given substrate of variation, a selection process is possible. Second, the reduction of variability contingently on reinforcement is counterintuitive with the assumption that variability can be increased with reinforcement process.

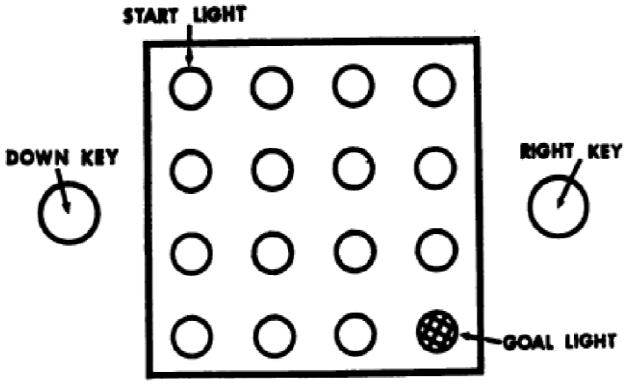



**Figure 5.** Illustration from Vogel et Annau (1978). "A peck on the right key moved the lit position one column to the right and a peck on the down key moved the lit position one row down. Moving the lit position from the upper left position to the lower right (goal) position produced access to food. More than three responses on a key resulted in a blackout."

Actually, these two aspects of behavioral variability gave rise to the next step of our investigation. The previous studies investigated the influence of environmental variables on the level of variability of operant responses. This starting point is essential because it shows a strong interest in behavioral variability. Indeed, this context for research is important because first, to study the relation between behavioral variability and operant conditioning, one has to operationalize and experiment variation as a dependent variable—or at least as a variable measurable. Second, when the tradition has put variability aside, this first step paves the way for further research. It demonstrates that behavioral variation can be affected by environmental contingencies. The next section investigates if behavioral variation can be controlled with environmental contingencies. In other words, if behavioral variations can be controlled with its antecedents and consequences.

## 1.2.2 Is Variability an Operant Dimension of Behavior?

In a context in which data suggest that some schedules of reinforcement may reduce variability of operant responses and that others increased it, trying to condition behavioral variability turns at to be a challenge. The first attempts were carried out by Schoenfeld, Harris and Farmer (1966) with rats. The authors aimed at reinforcing the variability of inter-response time (IRT) of lever press. In their experiment, food was distributed to a rat if the interval between two lever presses were different from the previous. The results suggest that IRT responses variability can be conditioned depending on the established rules of reinforcement. These results were replicated by two studies (Blough, 1966; Bryan & Church, 1974). However, in all these experiments, reinforcers were distributed depending on either the percentage of switches between two keys (Blough, 1966) or the temporal difference between consecutive responses (Schoenfeld, Harris & Farmer, 1966). However, researcher addresses the following question: Is behavioral variation directly reinforced or is it an effect of changes in schedules of reinforcement? Indeed, one can argue that those simple responses are reinforced intermittently, and we previously described how change from a CRF schedule to intermittent reinforcement induces variability. Therefore, the fact that we reinforce the lever presser intermittently may produce the variability found in these experiments. In this context, one can assume that it is not reinforcement that strictly controls variability but the intermittence of the reinforcement. Dissociating between the effects of reinforcement and the direct reinforcement of variability has been the object of many investigations. As a reminder, to be considered as an operant dimension of behavior, variations have to directly be influenced by direct consequences and antecedents.

Inspired by the study of Vogel and Annau (1973), Schwartz (1982) tried to condition variable sequences of responses with pigeons. Actually, the author aimed to prevent repetitive patterns of behavior induced by CRF schedule by putting in place a reinforcement contingency which required variability. Pigeons had to emit four pecks on each of two keys. In variability requirement contingency, to get reinforced the last sequence had to be different from the preceding one. The author failed to demonstrate that variability can be conditioned. Moreover, he replicated data found in previous experiments that CRF schedule induces stereotyped behaviors (Schwartz, 1981). Schwartz explained those results by the fact that first stereotyped sequences are resistant to environmental modifications in a way that variability cannot

overwhelm the stereotypy of behaviors. Second, he argued that the limitation of the pigeons' memory is a variable which prevents them from memorizing different pattern sequences. These results are against those found with simple responses (Blough & Blough, 1968; Schoenfeld, Harris & Farmer, 1966). The inconsistence of the results on behavioral variability led Page & Neuringer (1985) to investigate the topic. The authors used an apparatus similar to Schwartz's (1980, 1982) with pigeons in order to reinforce variability in complex responses. The experiment consisted in reinforcing sequences of pecks on two keys. A sequence was defined as a series of eight left and right key pecks. To control behavioral variability, the authors created a lag N procedure which consists in reinforcing a response if it is different from the n previous. For instance, in a lag 5, pigeons had to peck 5 different sequences to get reinforcement. The second originality of this experiment is the way to solve the problem of intermittent reinforcement. In order to demonstrate that reinforcement control variability and not intermittency, the authors created yoked control design which consists in distributing reinforcement depending on the variable group but without defining variability contingency. The hypothesis is that if there is variability in the group in which variability is reinforced and not in the yoked group, it implies that the variable responsible for variability is the contingency and not the intermittency of reinforcement. Results of this experiment had great repercussions on further studies of behavioral variability. First, based on Schwartz's works (1980, 1982) the authors succeeded in demonstrating that behavioral variability can be reinforced. Actually, it offered a new way to dissociate the impact of reinforcement schedule and direct reinforcement of variability. Second, they showed that pigeons can behave in a quasi-random way in a lag 50. This result demonstrated that memory of the pigeon is not an impediment to reinforced variability. Lastly, the study demonstrated that to behave in a variable way, pigeons have to be constrained to do it.

Based on the different procedures and measures previously presented, literature offers a great pool of evidence that behavioral variability can be reinforced. The problem with dissociating the effect of reinforcement schedule and the direct reinforcement of behavioral variability has been investigated in several studies (Grunow & Neuringer, 2002; Machado, 1989, 1992; Neuringer, 2009). Grunow and Neuringer (2002) illustrated this dissociation in a study with rats. In their first step, the authors reinforced different level of variability (low, intermediate level and high variability) among four groups of rats. Behavioral variability was first under a continual reinforcement schedule and then was thinned to a Variable Interval (VI)

schedule of reinforcement. The results of this first step showed that direct reinforcement has more effect on behavioral variation than the frequency of reinforcement. This result confirmed the hypothesis of operant variability. Moreover, it demonstrated that directly reinforced behavioral variation is more efficient to control it than variability induced by schedule of reinforcement. Actually, direct reinforcement enables to control behavioral variability. Indeed, contrary to the effects of intermittent reinforcement or extinction, the response rate is not changed with direct reinforcement.

## 1.3 Investigating Operant Variability

Based on the different procedures and measures previously presented, we observed that reinforcement can control behavioral variability. Despite this demonstration, there are several operant characteristics of variability which to have to be investigated. First, an operant response is controlled by antecedent and consequences. Studies have demonstrated that behavioral variation can be controlled a discriminative stimulus. Second, operant responses are known to be affected with extinction process. The interesting part of these studies is that extinction induces variations. Well, one can ask the differences between reinforced variability and variations induced with extinction. Lastly, the relation between reinforced variability and induced variability have been investigated in the case of selection by consequences. Researchers address the following question "Is it possible to reinforce specific responses and at the same times variations"? The next section aims at presenting these different aspects of variability.

### 1.3.1 Behavioral Variability is Controlled by Discriminative Stimulus

Discriminative control refers to the presentation of a given stimulus which evokes a specific response. In the presence of a discriminative stimulus, a response is more likely to occur because of the history of reinforcement. For instance, in the absence of light and in the presence of a switch light, a subject is more likely to press the switch light. The latter controls the press response in the absence of light. Any operant response can be controlled by its antecedent and consequence. In this context, researchers assume that because behavioral variability can be controlled by consequences, it can be by its antecedent. Cohen, Neuringer and Rhodes (1990) carried out an experiment in which long evans rats were reinforced to emit

either variable or repeated responses two levers, Left (L) and Right (R). These two contingencies were signaled with two discriminative stimulus: colour changes above and on the top of the ceiling. In the repetition, rats were rewarded to emit the same sequence (LLRR) when the floor was illuminated. In the variable condition, rats were reinforced to emit variable responses according to a lag schedule when the top of the ceiling was illuminated. One interested result is that both stimulus discriminative controlled the rat responses. In order to demonstrate the effect of reinforcement, Denney and Neuringer (1998) carried out an experiment in which rats were reinforced to emit variable behavior following the presentation of a discriminative stimulus. In a yoked group reward were distributed regardless of the variability criteria following the presentation of different stimulus. Results of this experiment demonstrated that an antecedent stimulus associated with reinforcement control the level of variability. Considering that variability is an operant dimension behavior implies the control with antecedent and consequences, but it implies too that stop reinforcing operant variability should affect level of variation. As previously introduced, extinction is one interesting part to understand operant conditioning. We can mention two main ways to create behavioral variability. We can reinforce it, using specific consequence which reach a given criterion of variability or we can withdraw consequences after a response which were previously reinforced.

### 1.3.2 Behavioral Variability, Extinction and Selection by Consequences

As mentioned earlier in this section, researchers were also interested in the effect of operant extinction on behavioral variability. As a process, operant extinction is known to affect operant response by producing a decrease in the probability of apparition of response, but before that an increase in its level of variations. Also, as the two produce behavioral variability, a systematic comparison between the two was conducted by the authors. For instance, Schwartz (1981) investigated the effects of extinction on behaviors which were previously reinforced in a CRF schedule. He found that responses which were more likely emitted in a reinforcement phase keep the same probability in extinction phase. This finding is counterintuitive because on the one hand variability increases during extinction. In the other hand, distribution and sequences seems to remain stable. Assuming that variability is mostly defined by the degree of unpredictability, how does stability appear in variable pattern?

Neuringer, Kornell and Olufs (2001) studied the effect of extinction on both behavioral variability and repetition. Based on the different demonstrations that behavioral variability can be increased by reinforcement (e.g. Page & Neuringer, 1985) and by extinction process (e.g. Antonitis, 1951), the authors investigated the effects of extinction on variations which were previously reinforced. Rats were reinforced to emit sequences of responses on three operanda (i.e. Two responses keys and a lever press) based on a variable, repetition or yoked contingency. In the variable contingency, rats were reinforced for the emission of sequences which were emitted less on 5% of the time. In the repetition contingency, reinforcement was distributed for the emission of a target sequence. Lastly, the yoked contingency, reinforcement was calculated upon the two previous contingencies (e.g. variable and repetition). The experiment was divided into two phases, a training phase and an extinction phase. Results showed that in all case, variability increased in the extinction, but it appears that the frequency of some sequences remains stable. If we look at the data closer we can observe that U-value (i.e. which indicates the level of variability) is high in the var-group during the reinforcement phase, during extinction, there is no significant increase. However, the var-group showed lower U-value compared to the var-group but increased consistently in the extinction phase. To test the stability of responses, the authors investigated the distribution of sequences, they observed that to extinguish variable responses remain the structure of response intact. This apparent stability is important because it implies that some responses which appear in extinction are already in the organism repertoire. Extinction does not eliminate responses which have been learned but enlarge the number of possibilities. However, this experiment seems to confirm that a certain degree of stability is possible when dealing with variability, which is a very paradoxical finding.

### 1.3.3 Operant Variability and Selection by Consequences

From the studies mentioned above, it became evident that behavioral variability can be considered as a form of operant behavior. Variability can be changed and increased with contingent reinforcers, controlled by stimulus discriminative, and is also affected by operant extinction, that is, when reinforcers are no longer delivered. In previous sections, we presented how several authors have made a parallel between operant conditioning and selectionism. According to this perspective on human and animal development, a class of operant responses will be selected by contingent reinforcers, while other responses will be extinguished (because they do not reach the “criteria” imposed by the contingency), changing the general pattern of

subject responses. From this, we can ask how the level of behavioral variability affects the selection of a new pattern of responses. In other words, does a specific level of behavioral variability can help in the acquisition of a new operant response? As we will see in next sections, this issue has important applied and clinical consequences, notably for patients with developmental disorders, and in which stereotyped and non-variable behaviors are known, disrupting the acquisition of new skills.

Pryor, Haag and O'Reilly (1969) were the first researchers who investigated the relation between reinforced variability and the acquisition of new complexes responses with animals. In the study, porpoises were trained to emit new topography of responses. Novelty was defined as a behavior which never observed in a given context and was not developed by shaping process. The results demonstrated that at the end of the experiment, porpoises emitted behaviors which were more and more complex. Furthermore, the experimenters observed behaviors which were never performed for the entire specie. In the same time, the authors noticed that once simple behaviors were reinforced, complex behaviors were less likely to emit. This result suggests that: first to emit simple behaviors are easier than emit complex ones. Second, it suggests that complex behaviors can be selected by environmental constraints. Despite its originality, this study presented a limit which was the way to define and operationalize complex behavior and novelty. Actually, there were only qualitative and subjective tools to characterize novelty.

Many years later, Neuringer (1993) proposed a different way to investigate variations and selection by consequences. His experiment consisted in reinforcing sequences of four responses on two levers presses (i.e. right and left). This experiment superimposed two contingencies in which both variability and a specific target sequence were reinforced. In order to induce variable patterns, Neuringer reinforced sequence of four responses only if it differed from the 5 previous. In parallel, one of the 16 sequences was defined as the target sequence. Reinforcement were distributed regardless the variability criteria and whenever this target sequence occurred. However, in all others cases the variability contingency was carried out. These two contingencies enabled to superimpose both variation and selection by consequences. The results of this experiment showed that first, rats emitted sequences variable and secondly that the frequency of the target sequence increased significantly from the baseline.

In a second experiment, the author manipulated the difficulty and assessed its influence on variation and selection. The difficulty of the sequences was defined across three target sequences, easy, intermediate-difficulty and difficult. The difficulty of the sequence was *a priori* assumed, the easy sequence target was "LLLL", the intermediate difficult sequence was "LRRR" and the difficult one was "LLLR". Using the same procedure described previously, the results showed that easy sequences were most likely emitted but the difficult sequences were never emitted. These results can be explained by the relative frequency of reinforcement. On the one hand, variable behavior and easy sequence are more likely reinforced, on the other hand, difficult sequence, because of their low relative frequency are less likely to be reinforced. In order to solve this problem Neuringer modified his variability contingency. Actually, he used an interval schedule of reinforcement in which reinforcement was provided on an average of 60 seconds if the criterion of variability was reached. By applying this contingency, the authors aimed to fade of the level of reinforcement and to equilibrate its relative frequency. Therefore to summarize this last experiment, first, rats were concurrently reinforced for the emission of variable behaviors on a VI 60s. Second, in parallel they get reinforced for the emission of an easy, intermediate or difficult sequence. The results of this experiment showed that all degrees of difficulty can be reinforced while variability is reinforced too. In other words, this experiment demonstrated the possible relation between variation and selection by consequences. Actually, the selection of low probable sequence in a substrate of variation is a first step to understand behavioral changes. However, this experiment has a severe limitation which prevents our conclusion on the effects of reinforcement on selection and on variation. Indeed, when comparing the quantity of reinforcement in the control and in the experimental group, the authors noticed a larger amount of reinforcement in the experimental group. These differences have led to the assumption that rat's behaviors could be controlled by the different level of reinforcement. This limitation was the basis of the next study.

Neuringer, Deiss and Olson (2000) studied behavioral variability with rats in the acquisition of a difficult target response. In their experiment, rats had to press two levers (LR) and a key (K) to obtain food. The authors concurrently reinforced the emission of a specific target sequence and non-target sequence depending on three contingencies (control, any, variable). Across phases, the authors picked different target sequences, from easy two-response to difficult five-response sequences. The control group consisted in reinforcing only the difficult target sequence while in the Any group, reinforcement was delivered for the target

sequence and also on variable interval schedule of 60-seconds (VI 60-S) for any other sequence. Lastly, the variable group consisted in reinforcing both the target sequence and variable sequences on a VI 60-S schedule. The results showed that all groups succeeded in the acquisition of the easy target sequences but that only the variable group succeeded in learning the difficult target sequences. This result led to the conclusion that behavioral variability facilitates the acquisition of difficult target response with animals. To understand the role of variability in the acquisition of novel responses, the same question has been investigated with human.

These results suggested that behavioral variability facilitates the acquisition of complex responses. The same type of results was found in the second experiment of Grunow and Neuringer (2002), the authors investigated how the different level of variability trained in the experiment 1 (low, intermediate, high) affect the acquisition of a difficult-to-learn sequence. The difficulty of a sequence was based on its frequency on the previous phase. For instance the LKK sequence was the target one because it was emitted at 0,037 relative frequencies. The results of the experiment 2 showed that the group which was previously trained to emit highly variable sequences acquired easier the difficult-to-learn sequence compared to the group low variability.

Studies of behavioral variability with animals enable us to have an overview on how a substrate of variation interacts with selection by consequences. These experiments emphasize the operant aspect of behavioral variability. There has been many investigations of operant variability with animal, literature offers a variety of methods of investigations. The next section aims at presenting the different ways to investigate operant variability.

## 1.4 Behavioral Variability and Human Studies

In everyday life, variations can be a way to explore the environment and to be in contact with new consequences which increases the probability to learn. In a puzzle box, animal seems to have more chance to learn how to open the door if it emits variable responses. The concept of trial and error learning is based on variability. For instance, in a game, using and mastering different strategies may contribute to increase the probability to win. Disciplines like art, are associated with high degree of variability (Neuringer, 2004). In some psychopathologies like

Autism or depression we can observe low pattern of variable behaviors which have great impact in the acquisition of adaptive and socially valid behaviors. Behavioral variability is related to creativity, problem solving, and acquisition of new responses. However, in all these situations, to control behavioral variability may be a challenge to understand human behavioral changes. However, there have been few studies experimentally investigating behavioral variability in humans. Investigations on the topic can be divided into three parts. First, the question of the operant aspect of variability. Second, the relation between controlled variability and response selection. Lastly, the relation between variability, developmental disabilities and psychopathologies.

### 1.4.1 Operant Variability with Humans

Maltzman (1960) was the first who successfully showed that human can be trained to generate variable response when asked to do. In this study, subjects were asked to generate free associated responses to a stimulus word. In a control group, subjects were asked to give free associated response to a stimulus word without constraint. In the experimental group, positive feedbacks were distributed when 5 different responses were given to the stimulus word. Feedback is any stimulus presented contingently to a response. Results showed that experimental groups emitted more low-probable responses than the control group. Otherwise, the author concluded that experimental groups showed higher originality than the control group. This first experiment provided evidence that feedback can be a source of variability. However, if the demonstration that variability can be trained is convincing, there is no evidence that reinforcement played a role. In the same way, other studies from Goetz and Baer (1973) succeeded in affecting variable behaviors with humans. In the first part of their experiment, children were reinforced for the block build construction that differed one from other. Second, children were reinforced for identical block build construction. The results of the study suggested that both repetition and variability can be controlled by consequences. Similarly to Maltzman's experiment (1960), the studies did not dissociate the effect of direct reinforcement and instruction. In this context, it is not possible to conclude that reinforcement is responsible for variability.

More recently a convincingly demonstration was brought by Ross & Neuringer (2002) who directly reinforced variability of three dimensions of an operant response. In the

experiment, subjects had to draw rectangles on a computer screen. The dimensions of response which were reinforced were the area of the rectangle, its location and its shape. In the first part of the experiment, subjects were reinforced to vary these three dimensions responses. In the experimental group reinforcement was distributed depending on the variability criterion. In the control group, the authors used a yoked procedure. In the second part, repetitive patterns of drawing across the three dimensions responses were reinforced. Results showed that behavioral variability and repetition were controlled by the contingencies of reinforcement. This experiment is one of the first to demonstrate convincingly that behavioral variability can be controlled by its consequences. This demonstration has been replicated across different dimension of responses like ocular movement (Paeye & Madelain, 2014), response keys (Stokes, Lai Holtz, Rigsbee & Cherrick, 2008; Doolan & Bizo, 2013), vocalizations (Esch, Esch & Love 2009). For instance, Paeye & Madelain (2014) carried out an experiment in which subjects had to find a target among distractors. Actually the authors manipulated the finding of the target in order to obtain specific saccadic amplitudes. They found that when subjects were required to emit saccades of rare amplitudes to display the target, variability increased. In the condition of frequent amplitude, variability decreased. Lastly, when no contingency was put in place with the same rate of reinforcement—yoked group— variability was not changed. Literature offers a panel of demonstration that behavioral variability can be controlled by antecedent and consequences. Several experiments (e.g. Wasserman, Young & Cook, 2004) have demonstrated that variable behaviors can be evoked by specific discriminative stimulus like tones, color changes etc… Considering that behavioral variation can be controlled by antecedent and consequences is the first step to study variability as a dependent variable. Considering, that based on the analogy of Skinner variation is a basis upon which selection is possible, we can ask to what extent operant variation plays a role in the acquisition of specifics responses.

### 1.4.2 Operant Variability and Selection by Consequences

In applied and experimental settings, shaping process is one way to observe the importance of varying in the acquisition of novel responses (Galbicka, 1994). The functional relation between responses and environmental contingencies sometimes leads to the apparition of novel responses. In this thesis novelty can be defined as responses which has never been observed in the behavioral repertoire of an organism (Maltzman, 1960). According to Skinner

(1938), the operant shaping process illustrates the importance of variable substrate in selection by consequences. In this process, the topographies of successive behavioral approximations are differentially reinforced until the apparition of a specific target response. Differential reinforcement – which is the main component of shaping – consists in reinforcing only specific topographies of responses within a response class and placing on extinction the other responses that do not meet the criteria. This balance between reinforcement and extinction is the basis upon which operant shaping is possible. The way a child learns to emit novel verbal behaviors is an instance of an operant shaping process. At birth some vocalizations are selected by enabling either the access to an appetitive stimulus or the removal of an aversive situation. The idea is simple, among a large pool of possibility, certain responses can be shaped by environmental contingencies. Because of environmental constraints, specifics topographies of vocalizations may be selected when they approximate the standards of the community. When these approximations are selected, the behaviors that do not meet this standard are not followed by consequences anymore. Based on this differential reinforcement process, verbal behavior is shaped by environmental contingencies. The logic of operant shaping process is described in *Science and Human Behavior* (Skinner, 1965). Shaping is a process implied in behavioral changes. At birth, a newborn has a limited repertoire because of the few possibilities of interactions, for instance communication is realized with facial expressions and unintelligible sounds. However, the interactions between the organism's behavior and the environment lead to the acquisition of novel responses. These responses can be considered as more complex just because they enable to have access to more possibilities for the child. In this thesis we will define complexity and simplicity of response according to their effect on environment. We assume that there is no functional difference between a lever press maintained by the access to a food deliver and an online order to get delivered. Both behaviors are maintained with the access to a specific consequence. However, to order food can be considered as a complex behavior because it is composed with simple responses which put all together enable a large panel of possible interactions with environment (Skinner, 1938).

There have been very few studies investigating variability and selection by consequences. In fact, we can mention two main studies with human. First Maes & Van Der Goot (2006) based on the works of Neuringer, Deiss & Olson (2000), investigated how selection of operant variability affects the acquisition of complex behaviors. Maes and Van der Goot (2006) studied concurrent reinforcement of behavioral variation in the acquisition of difficult

target responses. In their study, participants had to emit sequences in a computer game to obtain positive feedbacks. For all participants, the main way to obtain positive feedback was to emit a difficult target sequence. To operationalize the difficulty, the authors picked a sequence that was emitted at a rare level in a previous study (Maes, 2003). To concurrently reinforce behavioral variation and the difficult target sequence, the researchers created three feedback contingency groups (Variable, Yoked and Control). In all three groups, the difficult target sequence was systematically reinforced. In the variable and yoked groups, other sequences – called non-target– could be reinforced. In the variable group, reinforcement was provided on the basis of two criteria: the non-target sequence had to be different from the preceding two sequences and its relative frequency had to be below a given threshold. In order to increase behavioral variability, the authors manipulated a threshold value based on the relative frequency of responses (i.e. ranging from 0.25 to 0.03). In the yoked group, positive feedbacks for non-target sequences were provided according to the obtained reinforcement rate of the variable group.

Results showed that participants in the control group had a better performance than the variable group, which is inconsistent with the animal studies (Neuringer, Deiss, & Olson, 2000; Miller & Neuringer, 2000; Grunow & Neuringer, 2002). There have been three assumptions to explain these differences. The first explanation would be that the methodological differences between the experiments yielded this unexpected outcome. The second reason presented by the authors was that the positive feedback did not control the behavior of the participant. In fact, the authors argued that feedback can be considered as a less powerful reinforcer than food used with deprived rats. The third assumption can be viewed in continuation of the second reason. The authors assumed that behaviors were not controlled by the contingencies but by rule-governed behavior. Because of the low value of reinforcement, participant might create rules which biased the experiment. In fact, one issue commonly observed with human experiments is the dissociation between rule-governed behaviors and contingency-shaped behaviors. Considering the first term, behavior can be controlled by a rule which is a verbal statement— an antecedent— of an antecedent-behavior-consequence contingency. These antecedents can be auto-suggested rules or instructions of experimenters (Maes, 2003; Barba, 2012). In the second term, behaviors are considered to be controlled by direct reinforcement contingency (Catania, Shimoff & Matthews, 1989). The last suggestion focused on the very definition of what a difficult target sequence is. In most of the experiments, difficulty is defined on the rarity

of a sequence. The authors assumed that a sequence which is emitted at a low frequency is likely to be difficult.

In order to go further, Doolan and Bizo (2013) conducted a similar experiment to study to what extent behavioral variation is related to the acquisition of difficult target sequences. The authors aimed at examining some methodological aspects of previous study and assessing another procedure for concurrently reinforcing behavioral variability while learning a difficult target sequence. The idea was quite the same as previous experiments (Miller & Neuringer, 2000; Maes & Van der Groot, 2006). There were three groups: a control group in which only the target sequence was reinforced, a variable group in which reinforcement was provided either if a variable criterion was reached or if the target sequence was emitted, and a yoked group in which participants were paired with the reinforcement distribution of the variable group. Results showed that the control group was most likely to learn the specific target sequences compared to the other groups. These results confirmed the inconsistence with animal literature (Neuringer, Deiss & Olson, 2000). This is even more surprisingly because the methodology employed by the authors were very close to those carried out with animals (Neuringer, 2002). For the authors, the main variable to explain the different result is the species of the subjects. Similarly to Maes and Van Der Goot (2006), the authors explained that the difference of reinforcement and the rule governed behaviors may contribute to the differences between animal and human studies. However, globally the concordance of the results is still surprising considering, first, the data obtained with animals and secondly, the apparent importance of variability in learning. Actually considering the few experiment of behavioral variability and complex responses, one can argue that using different methodology, data with animals can be replicated, but till now, and to our knowledge there were no replication of those experiments with humans. The last main approach of behavioral variability in behavior analysis with human in behavior analysis is about developmental disabilities and psychopathologies.

### 1.4.3 Illustration of the Implication of Behavioral Variability in Behavioral Changes.

The absence of experimental evidence that behavioral variability facilitates learning is impediment to our analogy with selection by consequences. This observation is even more surprising considering our theoretical background (Neimy, Pelaez, Carrow, Monlux, & Tarbox,

2017). In fact, these results are counterintuitive considering the way we can observe behavioral change. For instance, in the language acquisition, the newborn who emits a certain level of variable vocalizations has high chance to learn to emit intelligible sounds and then to interact easily with his or her environment. Considering the number of parameters that have to be taken into account, to our knowledge, there had not been direct investigation of spontaneous variability and behavioral changes. Considering that experimental data are not convincing, we must look in another direction.

In fact, if we aim at studying the impact of behavioral variability in a natural environment, we have to look at psychopathologies in which we can observe abnormal patterns of variability. Indeed, even if we do not know much about the optimum level of behavioral variability and the selection of rare behaviors, we can observe the consequences of high or low level behavioral such as Attention Deficit Disorder (ADHD), depression and autism in developmental trajectory. The assumption is simple, if behavioral variability plays a role in the acquisition of new response, extremes levels of variability may affect developmental trajectories.

#### 1.4.3.1 Behavioral Variability and Psychopathologies: The example of ADHD

Children with ADHD manifest inattention, hyperactivity and impulsivity (American psychiatric association, 2000). These patterns of behaviors often lead to learning disabilities and social difficulties (Barkley, 1997; Crunelle, Veltman, Oortmerssen & Brink, 2013). Research in behavior analysis have consisted in studies on self-control, impulsivity (Hoerger & Mace, 2006), and discounting (Critchfield & Kollins, 2001; Wilson, Mitchell, Musser, Schmitt & Nigg, 2011). Most of these studies showed abnormal patterns of behaviors. Some researchers addressed the question of behavioral variability with children with ADHD. The first assumption was that a high level of variability may affect the occasions of learning which could explain the learning difficulties. However, one of the first studies on the topic presented by Wultz Sagvolden, Moser and Mozer (1990) proposed a study with Spontaneous Hypersensitive Rat (SHR). The authors assumed that SHR present similar characteristics with populations with Attention Deficit Hyperactivity Disorder (ADHD). Two commons patterns of behavior may interest us: Poor learning ability and hyperactivity. One limit with human studies is that ADHD is a pathology which is treated with medication and it seems that there is no study about ADHD, studying behavioral variability without medication (Neuringer, 2002). However, a study carried out by Mook, Jeffrey and Neuringer (1993) investigated behavioral variations with SHRs and

control rats. This study suggests two important points. First, SHRs showed high level of variation with or without variability contingencies. Second, SHRs fail to emit repetitive patterns when they are required to do it. These two results suggest that high (i.e. too much) level of variability is incompatible with the selection of repetitive behaviors which would explain difficulties of learning. Saldana and Neuringer (1998) directly observed the level of behavioral variability emitted by human ADHD and control participants. First, the study consisted in observing the level of variability emitted by the participants in a video game. Second, the authors reinforced variability on both groups. Results of experiments showed no differences in the level of spontaneous variability, in the second experiment, they succeeded to reinforce variable behaviors. However, this results was incompatible with animal literature but medication used on ADHD participants may be a source of bias. The authors recommended to go further in the study of variability to understand its impact on learning. Actually, if too much variability seems to be incompatible with the selection of target responses, the observation of low variable pattern may present the same limit. The next section aims at presenting the effect of low variability on behaviors.

#### 1.4.3.2 Behavioral Variability in Autistic Spectrum Disorders.

Theoretically, behaving in a repetitive way—not variable, may reduce the opportunity to be in touch with consequences present in the environment. This assumption has been investigated with psychopathologies in which we can observe low variable pattern. Depression is a psychopathology in which we can observe restrictive interest, lack of energy and repetitive thoughts (American Psychological Association). Experimentation confirm the lack of variability, for instance depressed subject tend to produce fewer solutions when asked for, compared to control participant (Lapp, Marinier & Pihl, 1992). An experiment of Channon and Baker (1996) observed that depressed participants generated sequences of responses less variable than control participants. Some research in behavior analysis asked if variability can be reinforced with depressed participants. Hopkinson and Neuringer (2003) carried out an experiment in which they observed that instructions and reinforcement are two possible ways to increase behavioral variability. They noticed that using these two procedures, depressed participants reach emitted the same level of variable behaviors than non-depressed participants. The authors suggested that increasing behavioral variability could be part of behavioral therapies. However, to our knowledge, such study has not been investigated.

Another psychopathology emphasizes the importance of variability in learning: Autism. Behavior analysis has a long tradition to work on Autistic Spectrum Disorder (ASD) (e.g. Lovaas, 1987). According to the Diagnostic and Statistical Manual of Mental Disorders 5 (DSM-5, 2015) ASD is defined by two criteria based on deficits of social interaction and repetitive patterns of behaviors. Restricted interest or activities and the emission of repetitive patterns of behavior are one of the main characteristics of ASD. Actually, we can observe that repetitive patterns of behavior are emitted during one's lifetime regardless of the natural modification of the environment (Riviere, Becquet, Peltret, Facon & Darcheville, 2011). These behavioral patterns are correlated with a mental retardation which has been diagnosed in 50 to 70% of individuals with ASD. From a selectionist perspective, the invariable pattern of behaviors decreases the probability to select new behavior. For instance, let us illustrate a shaping procedure which aims to reinforce the word "behavior". On one hand, a participant emits independently the sounds "B"; "A"; "V", "R". On the other hand, the other participant emits only and repeatedly (regardless of changes in the natural environment) the sound "B". We can hypothesize that the participant who performs various sounds will learn more quickly than the second one. This simple example illustrates that without variations, selection is impossible (Donahoe, 2012). The role of behavioral variability in acquisition of new behavior has not been directly experimentally investigated as presented in our example. However, there are some proofs that low variable patterns of behavior have great repercussion on development in ASD.

Mullins and Rincover (1985) studied how children with ASD maximize reinforcement in a card game. The experiment consisted in asking a child to pick one of five cards, which were discriminative stimuli for five different fixed ratio (FR) schedules of reinforcement (CRF, FR2, FR4, FR7 and FR10) which consist in reinforcing every *n* responses (e.g. FR1 schedule consist in reinforcing each occurrence of a target response). Results showed that, unlike the control group composed with neurotypic participants, children with ASD failed to maximize reinforcement. One possible explanation for this failure is that the emission of repetitive behaviors decreases the probability to be in contact with new contingencies. Actually, by emitting variable behaviors, the control group had the opportunity to experiment with each schedule of reinforcement contrary to children with ASD. Those results have been replicated and confirm the assumption of the role of behavioral variability in acquisition of new behaviors. Some research has investigated if variability can be controlled with children with ASD. For

instance, Miller and Neuringer (2000) have demonstrated that variability could be increased among people with ASD, in an experiment in which adolescents with ASD and control adults had to emit variable sequences. In a first step, reinforcement was provided independently of variability. The authors observed that participants with ASD emitted patterns of sequences less variable than the control group. Second, reinforcement was provided for the emission of variable behaviors. Results showed that behavioral variability increased consistently in both groups.

The different studies presented support the assumption that behavioral variability is an unexplored field that gain to be investigated with human. Considering that variability is a pertinent variable to understand behavioral change is the first step. In fact, more has to be done on the topic. Despite the recent experimental finding (Maes & Van Der Goot, 2003; Doolan & Bizo, 2013), observation in natural environment seems to demonstrate that variability is an important feature to understand behavioral changes.

## 1.5 How to Investigate Operant Behavioral Variability?

### 1.5.1 Procedures to Condition Behavioral Variability

According to Schoenfeld, Harris and Farmer (1966), if we aim at controlling variability, first we have to define specific criterion and secondly create reinforcement contingencies in which variability is possible. Since the publication of *Variability is an Operant* (Page & Neuringer, 1985), using different procedures, several studies have investigated and confirmed that behavioral variability can be considered as an operant dimension of behavior. The review *Operant Variability: Evidence, Function and Theory* (Neuringer, 2002) provides an overview of the different procedures and measures used in the investigation of behavioral variability.

The lag procedures are among the most common procedures used to reinforce behavioral variability both in experimental and applied settings. Page & Neuringer (1985) demonstrated that using a lag procedure, behavioral variability is controlled by its consequences but is also sensitive to discriminative stimulus. As a reminder, in a lag procedure, to be reinforced the last response has to be different from the N previous. The main advantage of a lag procedure is that

variability can easily be controlled by increasing or decreasing the length of the lag. In our example a lag 1 may be associated to a lower level of variability than in a lag 4 procedure.

Lag procedures do not require a predefined set of responses, considering that responses which were never observed are sufficient to lead to reinforcement. Actually, contrary to procedures based on relative frequencies, lag procedures do not need a large set of response. Considering this practical aspect, we can find a large panel of investigation in experimental setting as well as in applied setting.

Other procedures are used to investigate behavioral variability based on relative frequencies. These procedures assess the number of occurrences of a given response upon the total of responses emitted since the beginning of the experiment. This type of procedure may inform the probability of emission of a response and reinforce less frequent responses. Using this type of procedure Denney and Neuringer (1998) investigated with rats the control of behavioral variability with discriminative stimulus. In their experiments, one group of rats was reinforced to emit variable behaviors in the presence of a specific stimulus. The other group obtained yoked reinforcement in the presence of another stimulus. Both groups had to emit four responses on two levers, Left and Right. In the variable group, variability was created using a threshold. Reinforcement was distributed if the relative frequency of the current sequence was below 0.5. In order to weight recent sequences, the count of each number of sequences (here 16) was multiplied by a weighting coefficient. This coefficient enables to favor the least frequent sequence. Figure 6 from the article “Behavioral Variability is Controlled by Discriminative Stimuli” explains how this coefficient works.

**Table 1**
**Application of Weighting Coefficient**

| | | Sequence | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | LL | | LR | | RL | | RR | | | |
| Trial | Sequence | Weighted Frequency | Weighted Relative Frequency | Weighted Frequency | Weighted Relative Frequency | Weighted Frequency | Weighted Relative Frequency | Weighted Frequency | Weighted Relative Frequency | Weighted Sum | Reinforcement ($S^R$) Received? |
| Initial | | 1.0 | .25 | 1.0 | .25 | 1.0 | .25 | 1.0 | .25 | 4.00 | |
| 1 | LL | 1.9 | .40 | 0.95 | .20 | 0.95 | .20 | 0.95 | .20 | 4.75 | Yes |
| 2 | LL | 2.9 | .50 | 0.95 | .17 | 0.95 | .17 | 0.95 | .17 | 5.75 | No |
| 3 | LL | 3.9 | .58 | 0.95 | .14 | 0.95 | .14 | 0.95 | .14 | 6.75 | No |
| 4 | LR | 3.71 | .50 | 1.85 | .25 | 0.90 | .12 | 0.90 | .12 | 7.36 | Yes |
| 5 | RR | 3.52 | .44 | 1.76 | .22 | 0.86 | .11 | 1.81 | .23 | 7.94 | Yes |

Note—L, left; R, right. The weighted sum equals the sum of the weighted frequencies. The weighted relative frequency was calculated by dividing the weighted frequency by the weighted sum. The weighting coefficient (.95) was applied only if a reinforcement ($S^R$) was received, as shown in the far right column.

**Figure 6.** Use of relative frequency and weighting coefficient to reinforce variable behaviors, from Denney and Neuringer (1998).

In this experiment, Yoked groups were used to demonstrate that it is the reinforcement contingency which controls variability and not intermittent reinforcement. The results showed that behavioral variability can be controlled by discriminative stimulus. Procedures based on the measure of relative frequency have often been used to investigate behavioral variability (Blough, 1966; Machado, 1992, 1997).

## 1.5.2 A Measure of Behavioral Variability: The U Value

Measures of behavioral variability are mainly based on relative frequency. They enable the researcher to observe the distribution of the responses under investigation. At a certain level, when all relative frequencies have the same value, it implies a certain form of variability. U value is possibly the most common measure used in behavior analysis to assess variability (Barba, 2012). It indicates the entropy level of a distribution. Imagine an experiment in which subjects have to emit sequences on 3 different keys. U value is calculated with:

$$-\sum \frac{[RFi \times [\log(RFi)]}{\log 2(N)}$$

For i=1 to N. In this formula, N represent the total number of sequences (27 in our example), RF represents the relative frequency of each of the 27 sequences. When a single

instance of response is emitted, the result of this equation is 0 (which means that there is repetition of the same response). When the relative frequency is closed to equality, in other words when sequences are emitted with the same probability, the result of the equation is 1 (which means that there is the highest level of variability). A change in the U value is the reflection of changes in the distribution of responses.

## 1.6 Summary

Behavioral variability can be viewed as a continuum between repetitive behavior which consists of similar patterns of responses, and variable behaviors which consists of highly different responses. Independently of the perspective taken, psychology has more to do with stability than variability to explain behavioral changes. However, whatever the scientist does, variable performances in an experiment regardless of the independent variable in action are sometimes inevitable. The first question addressed in this thesis is to know how to deal with it. On the one hand, because of epistemological perspectives, traditional psychology considers variations as confounding variables. On the other hand, directly influenced by the functional perspective, behavioral approaches consider that variations are the result of environmental determinants. Based on the evolution theory analogy, this perspective assumes that behavioral variability might play an important role in behavioral changes. In fact, some disabilities, like autism, depression or ADHD, confirm that too low or too high a variability is incompatible with selection by consequences and therefore with learning. Considering that repetition is the lowest degree of variability, studies have often compared conditions which induce either response repetition or response variability. Research on behavioral variability can be divided into three parts: first, the operant question of variability in which we observe how far environmental determinants affect variability; secondly, the control of variability: is it an operant dimension of response like duration, frequency or temporal locus? Lastly, the relation between behavioral variability and learning. These studies mainly focus on animal experimentation and very few focus on humans.

The first part of investigations on behavioral variability dealt with the schedule of reinforcement and the variability of operant responses. If the relation between variability and selection by consequences seems to be obvious, behavioral literature demonstrated the opposite. Indeed, it has been shown that reinforcement process tends to induce repetition instead of

variations. The first experiments with animals investigated the variability of operant responses and how far the gradient of variation can be modified by specific schedules of reinforcement. It has been found that variability is reversible: some schedules of reinforcement reduce variability and on the other end some of them induce it. However, it has been demonstrated that consequences affect the structure of both repetition and variability.

The second part of the investigation on behavioral variability has focused on the operant character of behavioral variations. If variability could be considered as an operant, it would mean that it can be controlled by its antecedent and consequences. In other words, one could manipulate environmental contingencies to increase or decrease some degrees of variation. Using different types of procedure, these experiments confirmed that behavioral variability can be considered as an operant.

Thirdly, behavioral variability has been investigated about its relation with selection by consequences. Results with animals suggest that reinforcement of variability may favor the selection of complex responses. Replications with humans suggested opposite results. In fact, compared to animal experimentation, there have been few studies which investigated one of the three topics previously described. Further investigations should be led to understand one variable which seems important in the study of organism changes.

## 1.7 Experimental Goals

If selection by consequences has been the most extended subject of interest in behavior analysis, the variation upon which selection is possible appears to offer a large panel of possibilities to investigate. Considering that the subject has largely been investigated among different animal species (Page & Neuringer, 1985; Machado, 1997; Arantes, Berg, Le & Grace. 2012), our aim was to contribute to existing studies (Maes & Van Der Goot, 2006; Paeye & Madelain, 2014; Doolan & Bizo, 2013) with humans. Our thesis has investigated both repetitive and variable behaviors.

First, based on animal studies we investigated resistance to change of operant variability and repetitive behavior. Environmental changes are known to affect several dimensions of responses (e.g. response rate).. Based on animal investigations (Arantes, Berg, Le & Grace, 2012), we set up two experiments to assess the effect of environmental changes on both operant

variability and repetition. These two experiments consisted in reinforcing either variable or repetitive sequences of responses on a computer game. Once the target sequence responses were considered to be learnt, we introduced two major environmental changes. First, extinction, which consisted in no longer producing any consequences whatever sequences of responses were emitted. Second, non-contingent reinforcement, which consist in delivering consequences independently of the participant's behavior. Data analysis mainly consisted in measuring the level of variability during the training and during the disruption phase.

The second set of experiments aims at studying how operant variability affects the selection of rare behaviors. On the one hand, data with animals show evidence that behavioral variability facilitates the selection of rare behaviors (Grunow & Neuringer, 2000). On the other hand, experiments with humans seem to demonstrate the opposite: variability seems to interfere with the acquisition of complex behaviors (Maes & Van Der Goot, 2006; Doolan & Bizo, 2013). Our first experiment of this set consisted in training either variable or repetitive behavior in a computer game. Once the target conditions were considered to be learnt, participants had to learn three target responses which were considered to be rare. This experiment enabled us to examine how far training variable or repetition affects the acquisition of rare responses. Our results confirmed data which were previously observed in animal studies. The Second experiment we designed, is a pilot study inspired from Holth (2012,a) in which we investigated how variability across different class of responses can be transferred to a class that has not been emitted before. In this pilot study we manipulated two mains variables: First, we used different operanda to investigate different responses classes, second we manipulate the value of the consequences in order to assess their effect on variations.

# 2. Chapter 2: Variability and Resistance to Change

## 2.1 Repetition and Variability: the Case of Resistance to Change.

As presented in the introduction, investigations on behavioral variability have demonstrated that it may be considered as an operant dimension of behavior (Page & Neuringer, 1985). Based on this hypothesis, researchers have compared how environmental variables affect repetitive and variable behaviors. In fact, as previously introduced, these two patterns are in the same continuum, and both can be controlled with antecedent and consequences. This assertion implied that it is possible to control different degrees of this continuum by manipulating environmental variables. Investigations of these two behavioral patterns in human suggest that it can be observed in the psychopathologies previously described – ASD, depression and ADHD (Neuringer, 2002). In fact, they have two similarities: first, in all cases, high level of variability or high level of repetitive behaviors have an influence on the acquisition of socially adaptive behaviors. For instance, stereotyped behaviors (i.e. emission of repetitive behaviors) observed in ASD seem to be an impediment to the development of socially adaptive behaviors (e.g. Peters & Thompson, 2015). Second, at different levels they tend to be persistent despite natural environmental changes (Lionello-DeNolf, Dube & Mcllvane, 2010).

Behavioral therapies have provided a large panel of treatments which consisted in replacing problem behaviors by socially adaptive ones (e.g Iwata, 1982). Overall, procedures have focused on consequence-based interventions (Napolitano, Tessing, McAdam, Dunleavy & Cifuni, 2006) which consist in increasing the emission probability of socially adaptive behaviors and decreasing the emission probability of problem behaviors. Recently, applied researches have proposed behavioral variability as an alternative adaptive behavior (Sh & Love, 2009; Napolitano, Smith, Zarcone, Goodkin & McAdam 2010; Rodriguez & Thompson, 2015). These studies demonstrate that behaving in a variable way can be an adaptive alternative to repetitive behaviors. However, replacing a problem behavior by an adaptive one is not such an easy thing to do. On the one hand, behavioral treatments have to propose environmental changes which can modify persistent problem behaviors. On the other hand, these socially adaptive

behaviors have to persist despite the new change which will occur in the environment. The first part of our thesis consisted in addressing the following question: To what extent could repetitive and variable behaviors persist despite environmental changes? Comparing the degree of stability in repetition and variability by altering environmental contingencies seems to be another challenge to understand behavioral changes in Human.

Resistance to change is one way to investigate response persistence. It consists in testing how environmental changes affects the emission of one dimension of response. Commonly, the response dimension investigated is the response rate (Nevin, Mandell & Atak, 1983). Experiments have consisted in observing how the response rate is altered when an environmental parameter changes. The first study with animals investigating resistance to change and variability, assumed that repetition could be considered as a default response and that operant variation is less natural (Schwartz, 1983). This hypothesis implied that whatever we do to reinforce behavioral variation, thinning reinforcement (i.e. altering environmental contingencies) would inevitably lead to the recovery of repetitive behaviors. The assumption underlined is that repetition is a default response: because of its stability, it should be more resistant to change than variable behaviors. In other words, when we stop to reinforce repetitive behaviors, if we changed the reinforcement rate or the reinforcer value, repetition should be less affected (i.e. more stable) than variable behaviors. These manipulations of environmental contingencies will be named disruptions. Understanding how far the manipulation of different disruptions affects the stability of behavioral variability and repetition is the aim of the following studies.

Mc Elroy and Neuringer (1990) investigated the effect of alcohol on repetitive and variable behaviors. In this case, alcohol is considered to be a disrupter because it is known to alter the performances of subjects (Brugger, 1997). The hypothesis is that if behaving in a repetitive way is a default response, therefore it should be more resistant to change than variable responses. In other words, when a subject learns to repeat the same response, alcohol should not affect his or her performance. In the experiment, rats were reinforced to emit sequences which were either variable or repetitive on two levers, Right and Left (i.e. L and R). In the repeat group, rats were reinforced to repeat one sequence, LLRR whereas the sequence of the other group was not reinforced. In the vary group, reinforcement was provided if the last sequence were different from the five previous ones. The results of the experiment showed that

alcohol did not affect the degree of variation emitted but impaired repetitive behaviors. In other words, the rats made more errors in the repeat group than in the variable group. These results seem to suggest that repetitive pattern of behaviors are not a default response. This experiment focused on inter-subject design. It consisted of comparison between two groups of rats. Behavior analysis has a long tradition of "within single subject design" in which it is possible to compare how repetition and variation within an experiment for a single subject.

Multiple schedule consists of two or more schedules of reinforcement operating at a given moment. Each component is signaled by a given stimulus. Figure 7 illustrates an example of multiple schedules of reinforcement. Imagine an experiment in which the subject has to press two keys (i.e. Left and Right). The multiple schedules would consist in alternating two or more schedules of reinforcement.

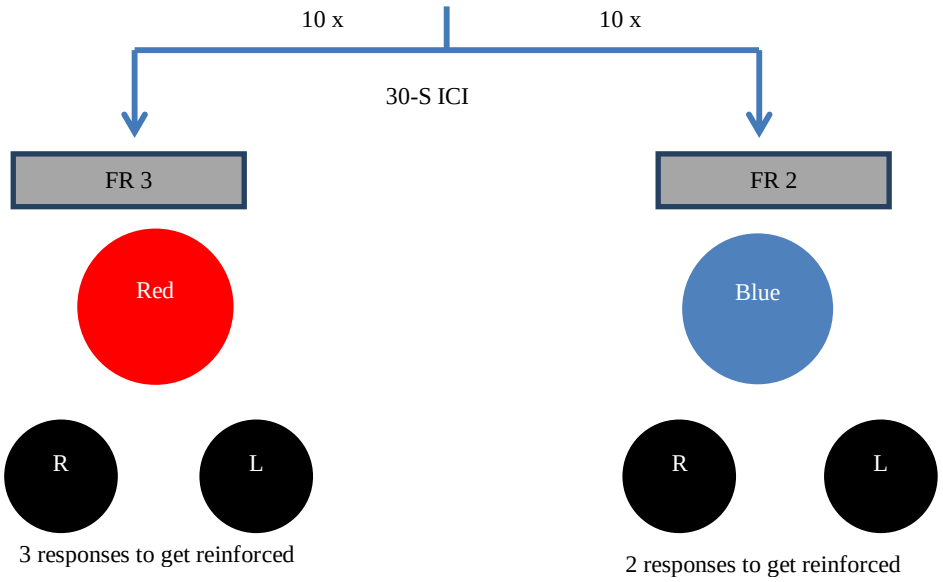



**Figure 7.** Instance of a multiple schedule of reinforcement with FR 3 and FR 2 schedules. FR 3 is signaled by a red stimulus and FR 2 by a blue stimulus. The two components are separated by a 30 inter-component interval.

Using a multiple schedule of reinforcement, Cohen, Neuringer and Rhodes (1991) studied the effect of alcohol as a disrupter on variable and repetitive responses. In the experiment, the multiple schedules were composed of a fixed response sequence (repeat) and a variable response sequence (var). The two components alternated. Once alcohol was injected to the rat, the authors assessed the degree of variability on the two patterns of behaviors and the percentage of reinforcers distributed. Results showed that variability in the repeat component

increased when alcohol was distributed even when the reinforcement rate decreased. The authors concluded that repetition is more susceptible to disruption than variable behaviors. These results confirmed the idea that repetition is not a default response and that the persistence of a pattern of behavior is dependent on the environmental contingencies. These two experiments (Mc Elroy & Neuringer, 1990; Cohen, Neuringer and Rhodes, 1991) used alcohol as a disruptor because it is known to directly alter behavior. In fact, in behavior analysis, disruption is traditionally related to three variables: manipulation of establishing operation, antecedent or consequence. Manipulation of motivating operation consists of altering the value of reinforcement (Catania, 1993). Manipulation of antecedent consists in modifiying the presentation of a given stimulus prior the apparition of a response. Lastly, manipulation of consequence consists of withholding or changing the contingency of the distribution of consequence.

There are several ways to disrupt a response using alteration of consequences (e.g extinction, non-contingent reinforcement). A study by Doughty and Lattal (2001) investigated the effect of consequences disruption and manipulation of motivating operation on the resistance to change of variable and repetitive behaviors. They used a multiple schedule of reinforcement in which two initial links led to either a variable or a repetitive component. Depending on a discriminative stimulus, pressing a key on a VI-20s schedule of reinforcement brings the pigeon to a variable or repetitive component. In the first condition, variability was reinforced depending on the relative frequency of the responses. The authors reinforced responses which occur only less than 5% of the time. In the repeat group, similarly to Cohen, Neuringer and Rhodes (1990), a target sequence was reinforced. When stability criterion was reached, the authors introduced two types of disrupters: prefeeding (i.e. satiation) and non-contingent reinforcement. The prefeeding procedure is a motivating operation which consists in satiating the subject by giving an important quantity of food before the experiment. Results of this manipulation should modify the value of the food as reinforce because of satiation. The second disrupter used, non-contingent reinforcement based on a Variable Time (30-s), consists in delivering reinforcement independently of the behavior on an average of 30-s. The results of the experiment showed that variable behaviors were more resistant to disruption than repetitive behaviors. In order to go further, the authors analyzed the organization of sequence of the responses emitted in the variable condition during the disruption phase. They observed that the structure of variability remains the same compared to repetitive responses. In other words we

observed similar patterns of sequence in both reinforced and induced variability. These results are interesting because it seems that when reinforced variability is altered we still observe stable patterns of behaviors. Similar results were found in further experiments with animals (Abreu-Rodrigues, Lattal, Santos & Matos, 2005).

Arantes, Berg, Le & Grace (2012) replicated the previous results and added extinction as a disruptor to examine the resistance to change for variable and repetitive responses. The authors reported similar results than those presented by Neuringer et al., (2001). They found that variability increased in extinction for repetitive responses and that increase was smaller for variable responses. Moreover, they found a significant decrease in the U value for the last session of extinction for the variable group. Their results confirmed that behavioral variability is more resistant to change than repetitive behaviors. Studies with animals seem to confirm that, first, behavioral variability is more resistant to change than repetitive behaviors. Second, results suggest that in an extinction phase, variability has a greater increase for repetitive behaviors than variable behaviors. These results are compatible with the observation that extinction increases variability. However, one of the most interesting results is that extinction does not alter the structure of variable behaviors which were previously reinforced.

Based on studies on animals (Neuringer, Kornell and Olufs, 2001; Doughty and Lattal, 2001; Abreu-Rodrigues et al, 2005, Arantes, Berg, Dien and Grace, 2012) we designed a set of experiments in which we investigated resistance to change for operant variable and repetitive behaviors. In a pilot study, we used points as consequences to target behaviors. However, in this experiment, behaviors were too variable in the way that reinforcement did not control the target responses. Moreover, we observed that the duration of the experiment was too long (almost one hour) and that participants lost interest before the end of the experiment. Based on these observations, we proposed to associate points with the decrease of time of the experiment. In other words, target behaviors were reinforced by the diminution of the duration of the experiment.

Two experiments were designed based on the pilot study. The experiment 1 failed to obtain conclusive results but enable us to design a strong design of experiment. In a multiple schedule, participants had to emit target sequences to reduce the duration of the experiment. The sequence had to be either variable if the discriminative stimulus was red or repetitive if the discriminative stimulus was blue. The experiment was divided in 2 phases. The first phase

consisted in training target sequences in the two conditions. The primary aim of this phase was to obtain higher level of variability in the variable condition compared to the repeat condition. The second phase consisted of a resistance-to-change test with extinction or non-contingent reinforcement for one of the two conditions (repeat or variable). In this phase we aimed at testing the degree of variability emitted when repetitive or variable patterns of responses are altered. Considering that extinction is known to increase the degree of variability, the primary question was whether variability increases in the same way in the variable and in the repeat condition. We assumed that providing reinforcers independently of the behaviors should reduce the level of variability. In fact, literature suggests that non contingent reinforcement have several effects on responses rates (Hagopian, Crockett, Deleon and Bowman, 2000). The main effect is that satiation which consists in devaluating the value of the reinforcement because of its presence independently of target response, leads to a decrease in response rate.

## 2.2 Experiment 1

### 2.2.1 Method

Ten undergraduate students of the University of Lille were recruited, four males and six females, aged 18 to 30. An information letter was sent by mail before the day of the experiment. All students signed a consent form prior to the experiment.

### 2.2.2 Apparatus

The experiment was conducted in an experimental room in the SCALab laboratory at the University of Lille. We used a computer with Windows 2000 software and programmed the experiment on Matlab®, using the psychophysics Toolbox extension (Brainard, 1997; Pelli, 1997). Participants sat on a chair facing the computer; to enter the sequences, they had to use the “A”, “Z”, “E” keys on the computer keyboard. The letter corresponding on the three keys were also displayed on the screen computer in three disks of 4 cm diameter. When the participant pressed a key on the keyboard, the corresponding key lighted up on the screen for 0.5 second along with a tone for 0.5 second. In the center of the screen above the three keys a circle either red or blue was displayed. If the circle was red, participants had to emit variable sequences, if it was blue, they had to emit repetitive sequences (see figure 8). A timer was

placed in the top right-hand corner of the computer monitor and started counting down when the experiment begun. Subjects were instructed that the experiment finished when timer value was *0*. At the beginning of the experiment the timer displayed *240 minutes*, after the emission of a correct sequence of 3 keys, it decreased by 5 minutes. Any wrong sequence was followed by a full grey screen for 2 seconds accompanied by a tone which lasted 0.5 second and no time was removed. The perturbation phase consisted of no longer diminishing the timer for extinction phase and reducing time non independently of the participant behavior for the non-contingent reinforcement phase.

### 2.2.3 Procedure

In order to limit the influence of the instructions on participant's behavior, only one information was screened on the computer for the entire experiment:

"*Thank you for your participation. You will play a game in which you have to decrease the duration of the experiment by doing sequences on the A, Z, E keys of this computer keyboard."*

Figure 8 introduces the interface of the computer game. In the experiment a trial was composed with the emission of ten sequences of three keys (A,Z, E). For one sequence, participants had 27 possible combinations. During the experiment, press on other computer keyboard was not recorded and did not produce consequences. When the large central disk was red, a vary contingency was put in place in which participants had to emit sequences which are different from each other. When the large central disk was blue, it was the repeat contingency in which participants had to emit identical to the first one emitted during the trial.




Variable condition Repeat condition

**Figure 8.** Illustration of the Interface used during the experiment.

Table 1 (see below) summarizes the experimental design used in this study. We used an alternative design in which two phases alternated: a training phase and an experimental phase. The training phase consisted of two conditions: variable and repetition which alternated too. A trial for a condition was made of ten sequences. Therefore, a condition contained ten trial and corresponding pattern is evoked by the color of the circle (red or blue). If the participant emitted correct sequences, reinforcement was delivered. The experimental phase contained two disrupters: extinction and non-contingent reinforcement. During these phases participants were assigned to one of two groups: disruption for variable condition or disruptions for repetitive condition. Disruptions phases ended when the participant did not press a key for 20 seconds.

**Table 1** : Illustration of the procedure of multiple schedule used in the experiment.

| | Variable group | Repetition group |
|---|---|---|
| Step 1 | Training phase<br>10 x 10 x<br>Variable condition Repeat condition | Training phase<br>10 x 10 x<br>Variable condition Repeat condition |
| Step2 | Experimental phase<br>Extinction in variable condition | Experimental phase<br>Extinction in the Repeat condition |
| Step3 | Training phase<br>10 x 10 x<br>Variable condition Repeat condition | Training phase<br>10 x 10 x<br>Variable condition Repeat condition |
| Step 4 | Experimental phase<br>VT 5-s in the variable condition | Experimental phase<br>VT 5-s in the Repeat condition |

**Training phase:**

*Variable condition*

When the circle was blue, to obtain reinforcement, the participants had to produce ten different sequences. During this condition we used a type of lag 10 design which consist in reinforcing sequences of 3 keys different from each other for 10 sequences. For instance, the first sequence emitted was reinforced, whatever it was. If the second sequence was different from the previous, reinforcement was delivered. Each correct sequence was continuously reinforced. A wrong sequence was defined as a sequence which was emitted at least once in the ten last sequences. It was systematically followed by a time out 3-s. At the end of the trial, the circle changed its color to signal the other condition.

*Repeat condition*

When the circle was red, to obtain reinforcement, the participants had to emit 10 identical sequences. For example, if they emitted AZE at the first sequence, each next sequences which are identical to AZE are reinforced. Each correct sequence was continuously reinforced by the diminution of time. Each wrong sequence was followed by a time out 3-s. Based on the pilot experiment, we observed that emitting repetitive sequence was easier than emitting variable ones. In order to try to obtain a similar reinforcement rate in both condition, when the participant get at least 80% of correct sequence for four trials (i.e. 40 last sequences), we yoked the consequence to the variable group. In another word, when the participant get wrong in the variable condition, no time was reducing for the next trial in the repetition condition. For instance in the fourth trial, the participant get only four correct sequence on ten. In the next trial of the repetitive condition, the participant get only four reinforcers on ten even if he did not mistake. At the end of each trial of ten sequences, the circle changed its color to signal the other condition.

*Criterion to shift from training to experimental phase*

A disrupter was introduced when the same number of reinforcement was distributed in each condition, and when there were 80% of correct sequences in the last four trials for each condition. Disrupters were targeted for one of the two conditions.

**Experimental phase**

*Extinction:*

Extinction consisted of the absence of consequence (no matter what the participant did). The time was not reduced even if the participants emitted correct sequences. The extinction phase ended when the participant no longer pressed key for 20 seconds.

*Non-contingent reinforcement 5-s:*

This phase consisted of a Non-contingent reinforcement in the form of Variable Time schedule of reinforcement. This schedule consisted in removing 5 minutes to the timer, on average of 5 seconds, independently of the participant behaviors. This phase lasted till the participant no longer press key for 20 seconds.

## 2.2.4 Dependent variables

First, to assess the influence of the disruption on our two target behaviors (repeat, variable), the reinforcement rate per minute was measured for the two training phases. Second, In order to measure the level of variability we analyzed the U Value for each condition in the training phase and for each experimental phases. U value was calculated for the 5 last trials (50 sequences) in each condition. We used the following equation:

$$-\sum \frac{[RFi \times [\log2(RFi)]}{\log2(27)}$$

We expected to obtain a level of variability close to 1 during the training phases for the variable condition and close to 0 for the repeat condition. To obtain more precision on variability, we observed the percentage of sequence used in the training phase and for the disruption phases. This measurement is related to U value. Considering that there was 27

sequences possible, we measured the number of sequences emitted by the participants for the different phases. High level of variability should be related to the used of many different sequences, on the contrary, repetition should be related to the emission of few different sequences. For each measure, we also individually observed data to study the different simple effects

## 2.2.5 Results

Figure 9 depicts the mean reinforcement rate for the two groups during the two training phases and for the two conditions during the four last trials. We did not expect a difference in the reinforcement rate between the two groups. A linear mixed model "group x condition x training phase" revealed no differences between groups $F(1, 8) = 0.008$, $p = 0.930$, no difference between training phases ($F(1, 24) = 2.723$, $p = 0.112$ and no difference between conditions $F(1, 24) = 0.515$, $p = 0.480$. This analysis showed that there is no significative difference of reinforcement between the two groups, conditions and training phases.

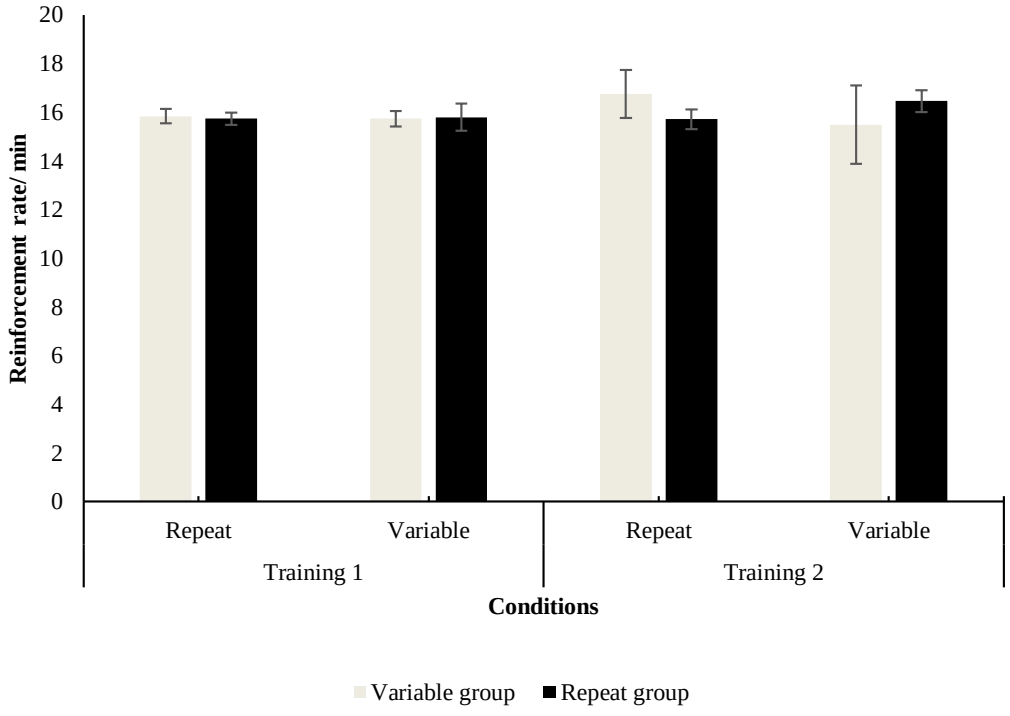



**Figure 9.** Reinforcement rate per minutes during the two training phases for the variable and repeat condition in the two groups (variable and repeat).

Figure 10 introduces the U value individually for each subject in the variable group during the two training phases. We can observe that the U value variable condition near to 1 and close to 0 in the repeat condition. Figure 11 introduces the U value individually for each subject in the repeat group during the two training phases. Same results are observed which implies that there are differences between the two conditions regardless of the group. Because the only difference between the repeat and variable group is in the disruption, we did not expect a different level of variability in the two groups. In fact, the only difference expected is between the variable and repeat condition. These results confirmed previous results with humans (Neuringer, 2002; Paeye & Madelain, 2013) which have demonstrated that behavioral variability can be controlled by discriminative stimulus.

Figure 12 depicts the U value for each subject during the training and the extinction phase for the repeat group. In the repeat group, we can first observe that during the training phase, U value never exceeded 0.33 for every subjects. During the extinction phase, the U value for subject 1, 2 and 3 is at 0 but for the subjects 4 and 5 it increased to 0.33. Figure 13 depicts the U value for each subject during the training and the extinction phase for the variable group. We can observe a slight increase of the U value for three subjects and a decrease for two subjects. Unfortunately, results in the Non-contingent reinforcement phase did not able to do pertinent analysis due to the absence of response. In this case, every subject emitted less than 30 sequences for this phase. To go further in our analysis, we looked at the percentage of sequences used in the different phases. This analysis is a complement to U value, it show the proportion of sequences emitted during the different phases. Figure 14 depicts the percentage of sequence used in the different conditions for the different phases in each group. First we can observe that whatever the condition, the repeat condition does not reach the 50% of sequence, even in extinction phase. This data is congruent with the U value where we observe that repetition is associated with a low U value. Second, we can observe that in the variable condition, participants used more than 50% of sequence in each phases. The lack of responses in the variable time phase of reinforcement prevented a pertinent analysis of the data.

### 2.2.6 Discussion

This first experiment aimed at studying the effects of environmental disrupters on trained variable and repetitive behaviors in humans. We can observe that using time reduction

work as reinforcement. Each correct sequence enabled the participant to obtain 5 minutes in the experiment. However, removing time as reinforcer can raise ethical concerns. We can assume that time decrease should act as negative reinforce, in this case, we assume that the experiment is "aversive" and that decreasing time negatively reinforce participant's behaviors. Considering that points is maybe one of the most common stimulus used as reinforcer in human literature (Maes, 2006), time reduction can be an alternative considering ethical concerns.

The first goal of this study was to train both variable and repetitive behaviors in the same experiment. Then, we aimed at measuring the degree of variability in both patterns of behaviors during training and disruption phases. Based on previous animal studies we used extinction and non-contingent reinforcement as disrupters. As a reminder, results with animals suggest that: First, variation is more stable than repetitive behaviors in extinction and non-contingent reinforcement phases. Second, that extinction does not increase variability of variable behaviors but does for repetitive ones. Lastly, literature suggests that extinction does not affect the structure of trained variable behaviors (Doughty & Lattal, 2001; Grace et al., 2012). We succeeded in obtaining high level of variability in variable condition and high repeatability in the repeat condition. In fact we can observe that participants emitted more than 90% of the sequences in the vary contingency and less than 30% in the repeat contingency. In order to train these patterns of behaviors, we used a lag procedure. We can notice that this procedure created high reinforcement rate. This might be an important variable to take into account because, as previously observed reinforcement contingencies influence degrees of variability. In this case, we analyzed how far extinction and non-contingent variability affect repeatability and variability of responses.

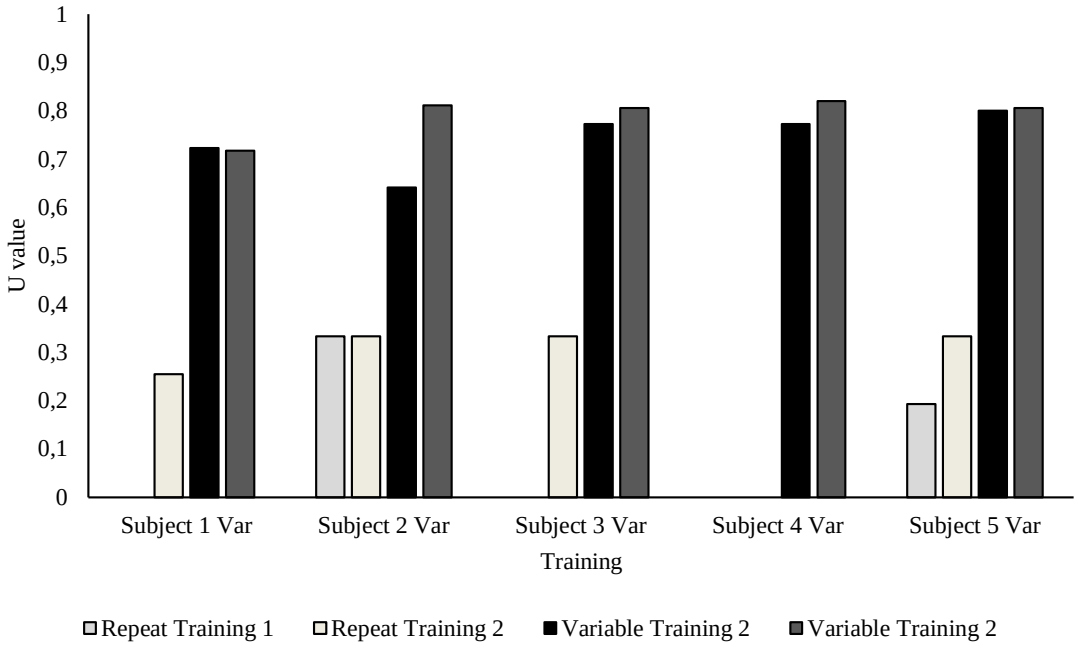



**Figure 10.** U value for each subject during the two training phase for the variable group

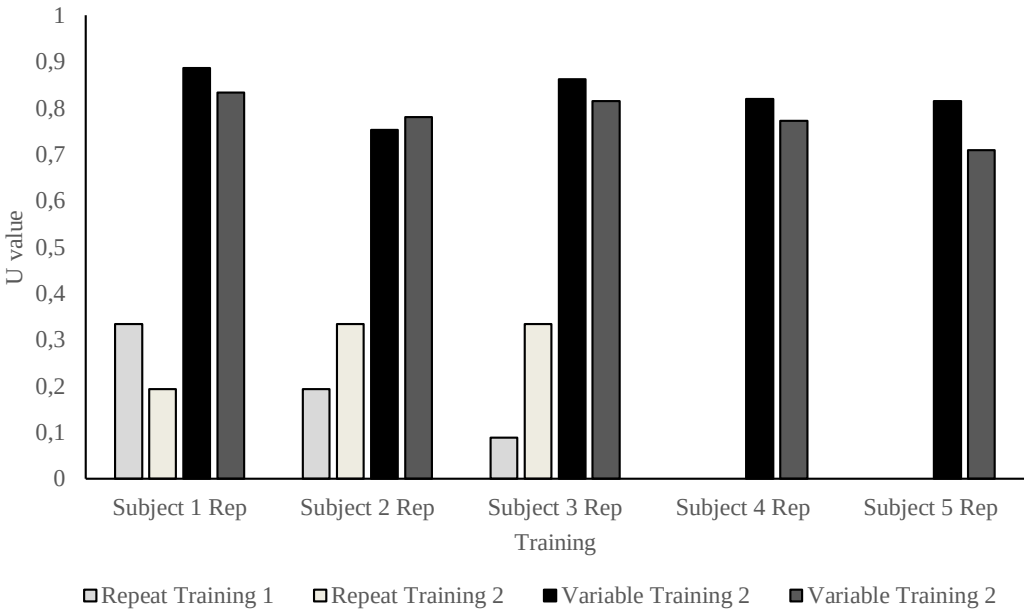



**Figure 11.** U value for each subject during the two training phases for the repeat group

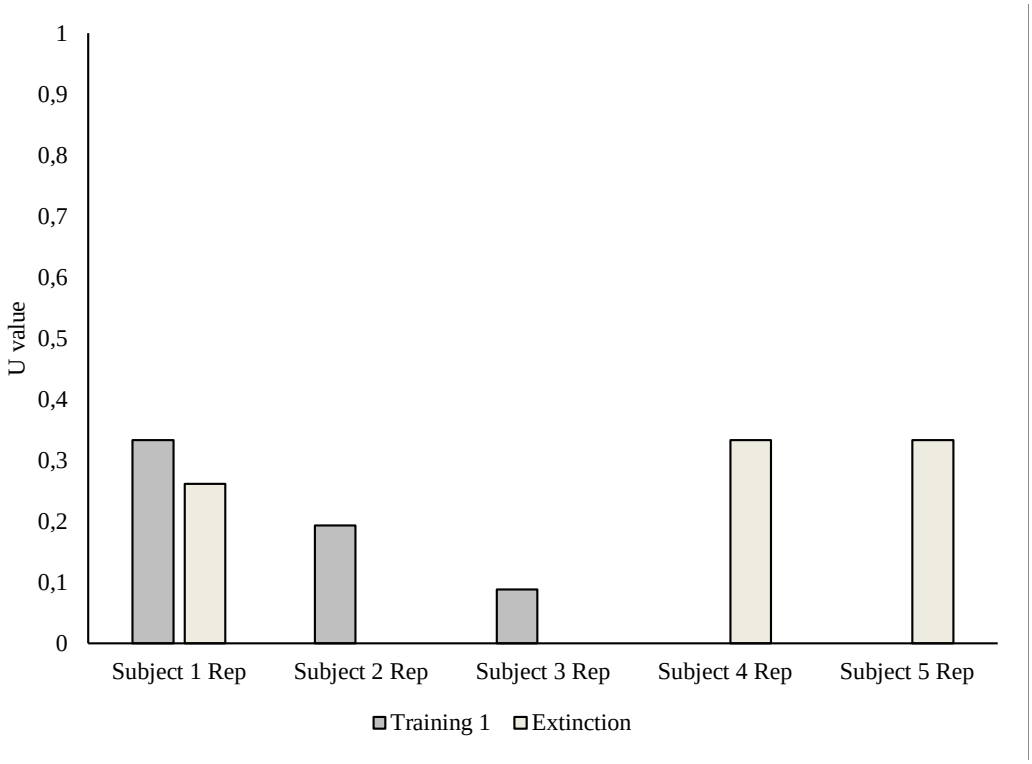



**Figure 12.** U value for each subject of the repeat group during training and extinction phases

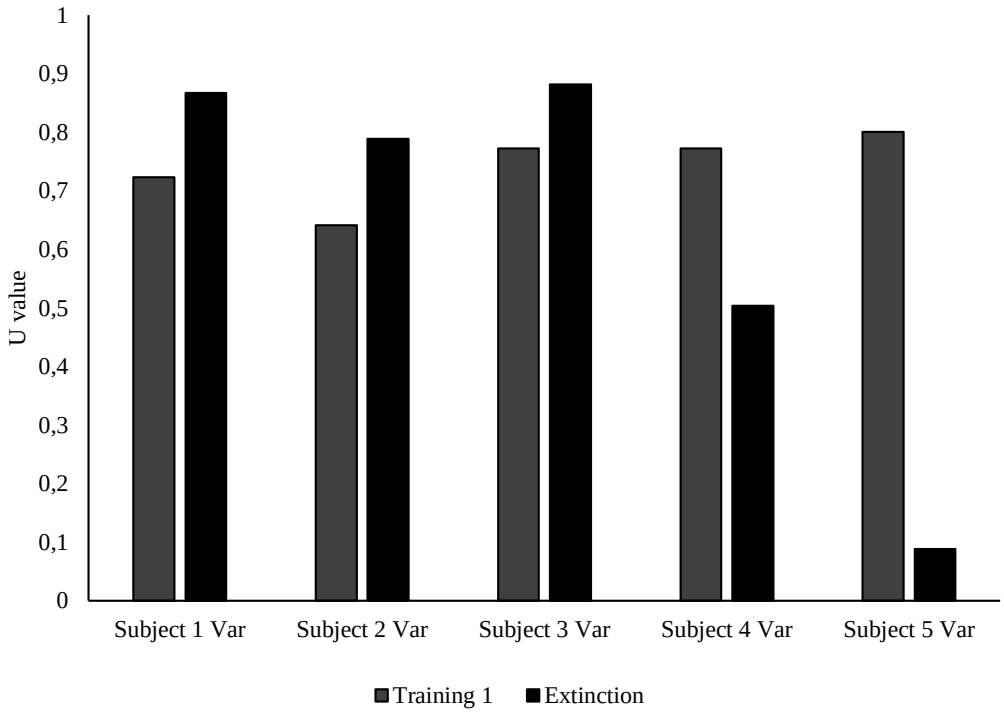



**Figure 13.** U value for each subject of the variable group during training and extinction phase

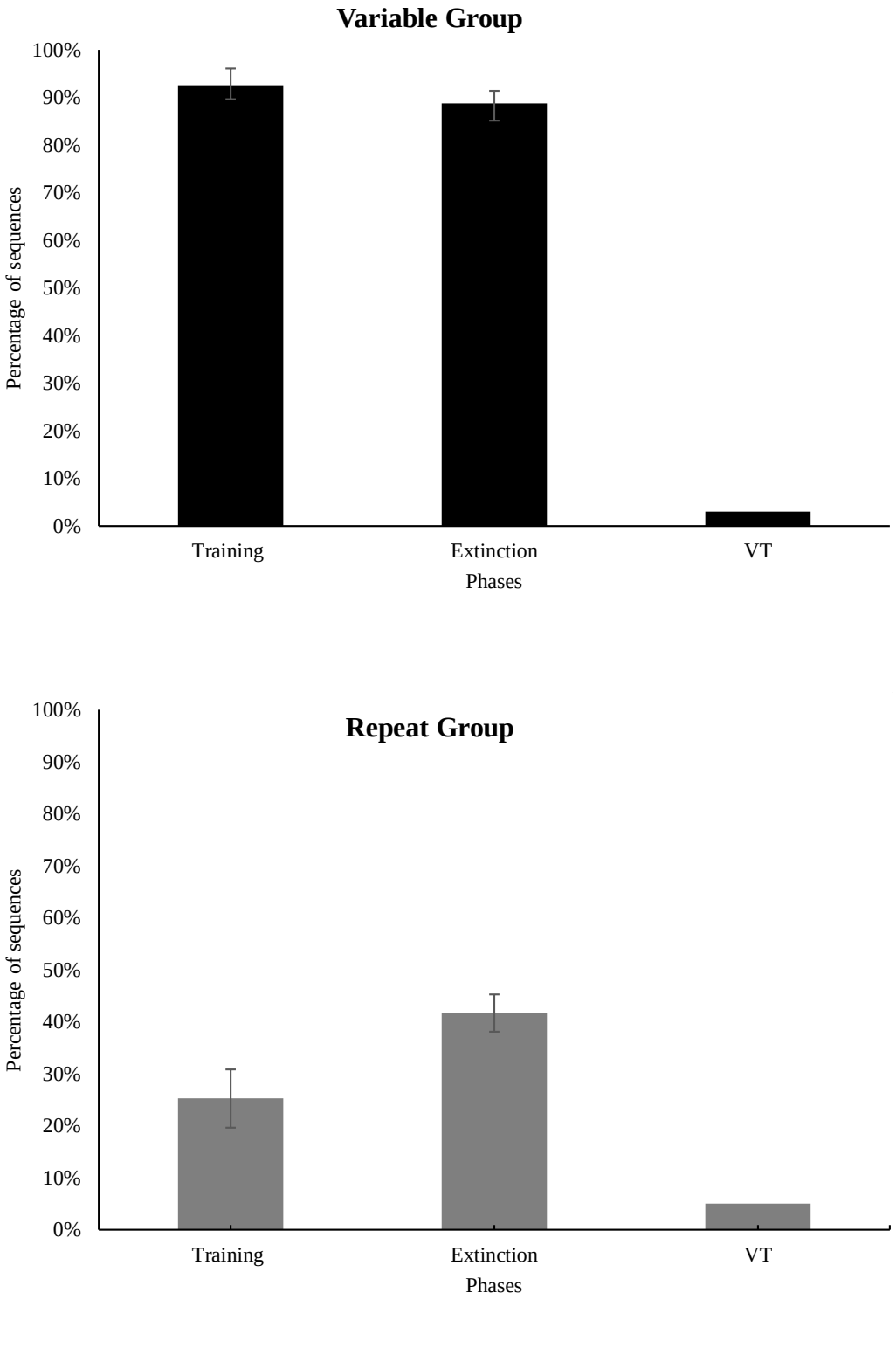



**Figure 14.** Percentage of sequence emitted in the Variable and Repeat group during the Training, Extinction and Variable Time schedule phases.

Extinction phase consisted in withdrawing reinforcement. This phase lasted until the participant stopped responding for 20 seconds. The first observation was that the phase was too long, participants were "stuck" at least for 15 minutes in this disruption phase. When we look at results in the variable condition, we can observe that for 3 of 5 subjects, there is a slight increase of the U value. These results are congruent with animal literature (Doughty & Lattal, 2001). The increase of the U value is very slight because at the beginning, the lag procedure produced high level of variability. However, interestingly, we can observe that for two subjects, the U value largely decreased from the training to the extinction phase. This result might be explained by the duration of this session for these two subjects (45 and 50 minutes in the extinction phase). As a reminder, in order to analyze data, we took 50 sequences to calculate the U value during the different phases and for each condition. However, in the extinction phase, these two participants emitted more than 400 sequences before to stop to respond. Therefore, our analysis might be garbled. In order to go further we looked at the percentage of sequences emitted by subject in the variable condition, only one participant emitted 100% of the sequence, the others reached 90%. The absence of increase in variability between the two phases for 3 subjects can be explained by a ceiling effect. Participants reached the maximum in the training phase.

In the repeat condition we observed that U value did not change from the training to the extinction phase. The result of this experiment seems to address several questions. First, we can observe that U value never exceed 0.30 in this condition. Second, there is a decrease of the U value for 3 subjects which means that these subjects emitted the same sequence over and over till they stopped, for the 2 subjects remaining, there was a slight increase of variations. Independently of the condition, in literature extinction is known to: first, increase the level of variability of operant responses, second to decrease response rate and therefore the level of variability (Mechner, 1958; Balsam, Deich, Ohyama & Stokes, 2000). Interestingly for all subject and in all conditions, extinction did not really affect the level of variability. This result is congruent with a study carried out by Schwartz (1981). In this experiment, the authors reinforced pigeons for emitting sequences of eight responses across left and right key. The only constraint which were put in place was that sequence must contain four responses on each key. It appeared that during the learning phase, pigeons learnt a dominant sequence. Then the author carried out an extinction phase and observed that this dominant pattern were maintained during extinction. Applied to our experiment it appear that pattern which were learnt in the training

phase were also maintained during the extinction phase. However, it appears that independently of the condition, dominant patterns appeared to be resistant to extinction.

Non-contingent reinforcement consisted in reducing time independently of the participant's behaviors on an average of 5 seconds. Unfortunately, the 5 seconds were too small, and participants stopped to respond too soon to examine data. Even if the results of this experiment were encouraging to study resistance to change of variability there are several biases which prevent us to conclude properly. First, the high rate of reinforcement provided in the training phase may affect the resistance to change in the extinction phase. Second, the criterion used to go from the disruption to the next phase may be too high. Lastly, the duration of the non-contingent reinforcement may explain why participants stopped to respond so quickly. The second experiment aimed at correcting the previous parameters and assess their effect on resistance to change of variable and repetitive sequences.

## 2.3 Experiment 2

Experiment 2 was the replication of the first experiment. Using the same instruction as in the experiment 1, in a computer game, using a multiple schedule, we trained both variable and repetitive sequences evoked by either a red or a blue circle. When target sequences reached a criterion of stability we introduced either an extinction or a non-contingent reinforcement phase. First, the difference between experiments 1 and 2 was in the way to generate behavioral variations. In the experiment 1 we used a lag design, in which a response is reinforced if it is different from the *n* previous responses. In the present experiment, to obtain reinforcement, subjects have to emit 10 different sequences. To our knowledge this procedure has not been tested with both human and animals. This way to create behavioral variability should provide a reinforcement rate which is less important than the previous experiment. Our aim was to assess such contingency on variability for the different disrupters. Second, we changed the criterion used in the disrupter phase which lasted for 5 minutes. Lastly, we increased the non-contingent reinforcement criterion from a VT5 seconds to VT15 seconds. Our primary question did not change: we aimed at assessing the effect of disrupters on trained variable and repetitive behaviors.

### 2.3.1 Method

Ten undergraduate students of the University of Lille were recruited, five males and five females, aged 18 to 30 years old. An information letter was sent by mail before the day of the experiment. All students signed a consent form prior to the experiment.

### 2.3.2 Apparatus

The apparatus was the same as in the experiment 1.

### 2.3.3 Procedure

The procedure was identical to the experiment 1. We used an alternative design in which two phases alternated: a training and an experimental phase. The training phase consisted of two conditions: variable and repetition. Reinforcement were distributed for 10 correct

sequences which composed a trial. The experimental phase contained two disrupters: Extinction and non-contingent reinforcement. During these phases participants were assigned to one of two groups: disruption for variable condition and disruption for repetitive condition. The first important change was in the training condition.

**Training phase:**

*Variable condition*

A blue disk was used as a discriminative stimulus for this condition. We used a new procedure in which participants had to emit ten different sequences to get reinforced. This procedure enabled us to provide reinforcement at the most every ten sequences (at the opposite, the previous lag procedure provides reinforcement at the most, for every sequences). A wrong sequence was defined as a sequence which was emitted at least once during the ten last sequences. It was systematically followed by a time out 3-s. At the end of the trial, the circle changed its color to signal the other condition.

*Repeat condition*

A red circle was used as a discriminative stimulus for this condition. Similarly to the variable condition, participants were reinforced for the emission of ten identical sequences. Based on the first experiment, we assumed that emitting repetitive sequence was easier than emitting variable sequence. In order to obtain the same reinforcement rate, when the participant emitted twenty correct sequences, we yoked the next trials to the variable group. In other word, if the participant emit an incorrect response in the variable condition at the sixth sequence, in the next repeat condition, no reinforcement was distributed, even if it was correct. An incorrect sequence was defined as different from the first sequence emitted during the current trial. It was systematically followed by a time out 3-s. At the end of the trial, the circle changed its color to signal the other condition

**Experimental phase**

*Extinction:*

Extinction consisted of the absence of consequence (no matter what the participant did). The time was not reduced even if the participants emitted correct sequences. The extinction phase lasted for 5 minutes and was followed by a training phase.

*Non-contingent reinforcement 15-s:*

This phase consisted of a Non-contingent reinforcement. More precisely, it consisted in reducing time on an average of 5 seconds independently of the participant behaviors. This phase lasted for 5 minutes. At the end of this phase, the experiment ended.

## 2.3.4 Dependent variables

We used the same dependent variable as the previous experiment: The U value, the relative frequency and the percentage of sequence and the rate of reinforcement in the training phase.

**Table 2**

**Summarize of experiment 1 & 2**

| Phase | Experiment 1 | Experiment 2 |
|---|---|---|
| **Training phase : Repeat condition** | Reinforcement is provided every sequences which are similar to the ten previous one. | Reinforcement is distributed if the last sequence is similar to the ten previous |
| **Training phase : Variable condition** | Reinforcement is distributed every new sequence which are different from the ten previous | Reinforcement is distributed if the last sequence is different to the ten previous |
| **Disruption 1 : Extintion** | Extinction ends when the participant no longer press kess for 20 seconds | ends at 5 minutes |

## 2.3.5 Results

Figure 15 depicts the mean reinforcement rate for the two groups during the two training phases and for the two conditions for the three last trials. Participants received an average of 0.6 reinforcers per minutes. As expected, the reinforcement rate is lower than the previous

experiment. We did not expect a difference between the two groups**.** A linear mixed model "group x condition x training phase" revealed no significative difference between groups F (1, 8) = 3.522, p=0.097, a significative difference between training phases (F (1, 24) = 5.103, $p<0.05$ and no difference between conditions F (1, 24) = 0.0791, p= 0.781. This analysis showed that there is no significative difference of reinforcement between the two groups and condition but there is between training phases. Except for the differences between training phases, these results are very similar to the experiment 1. However, the main difference is in the amplitude of reinforcement. As a reminder, in the first experiment, participants received an average of 15.7 reinforcers per minutes. Using this new procedure decreased the amount of reinforcement distributed during the training phase.

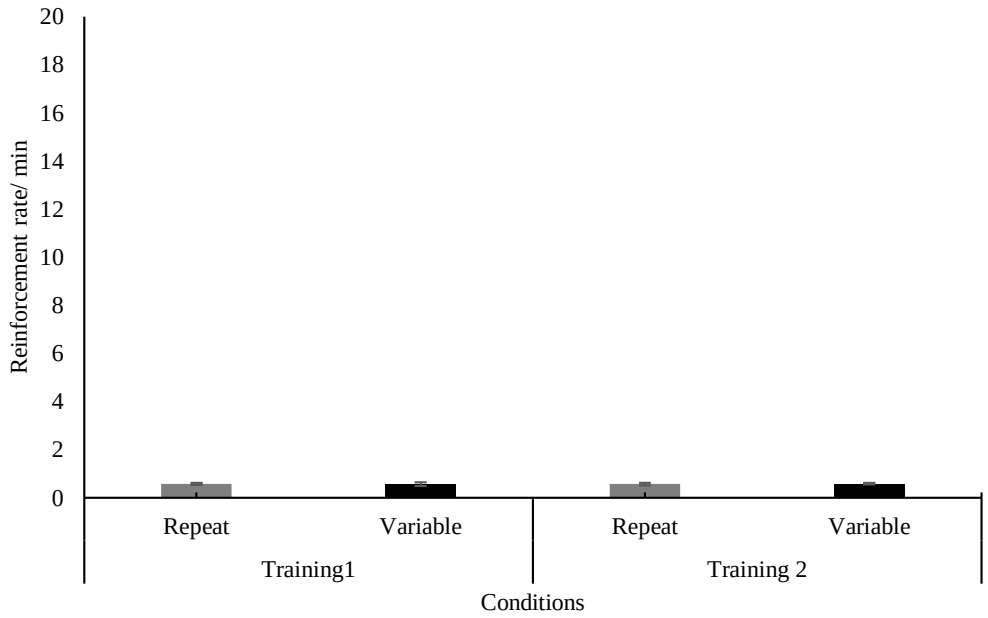



**Figure 15.** Reinforcement rate per minutes during the two training phases for the variable and repeat condition in the two groups (variable and repeat)

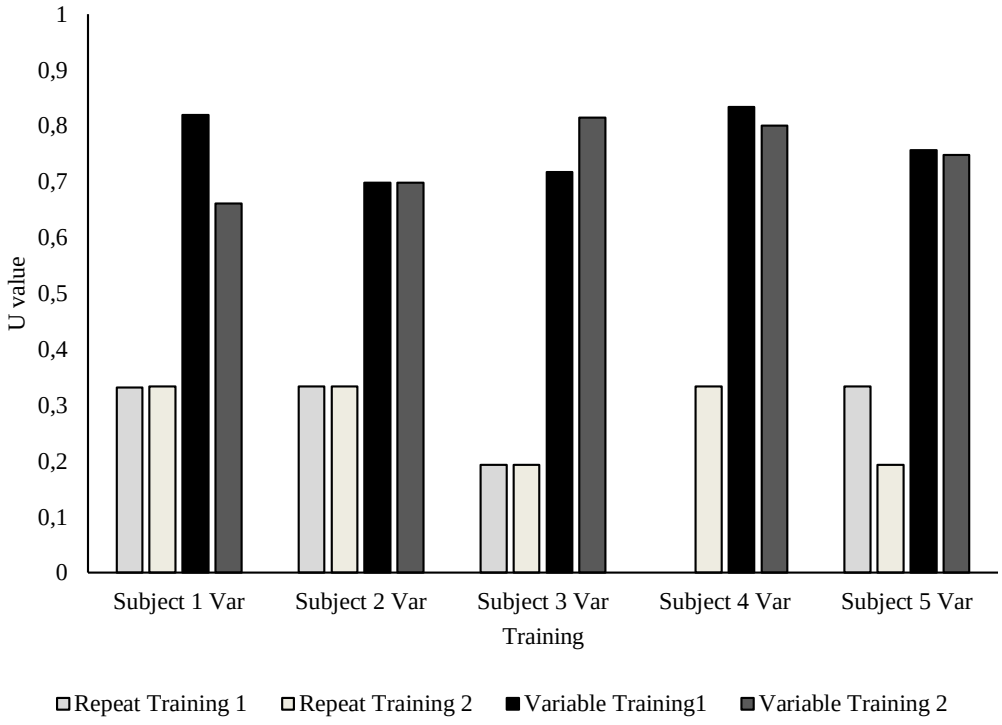



**Figure 16.** U value for each subject during the two training phase for the variable group

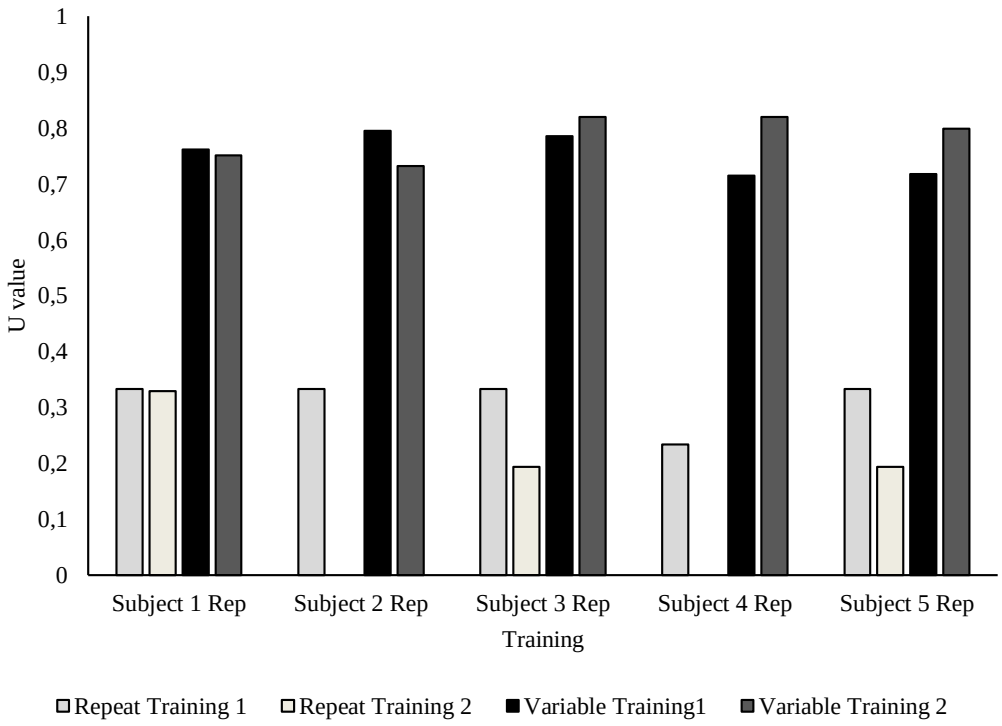



**Figure 17.** U value for each subject during the two training phase for the repeat group

Figure 16 introduces the U value individually for each subject in the variable group. Similarly to the first experiment, U value is close to 0 in the repeat condition and at 0.8 in the variable condition for both groups. Actually, we can visually observe a higher level of variability in the variable condition training (0.8) compared to repeat condition (0.1) independently of the group. The results found during the training phase are very similar to the previous experiment which means that our two procedures create a similar level of variability in the repeat and variable condition training. Figure 17 introduces the U value individually for each subject in the repeat group during the two training phases. Globally, we can observe the same level of variability for the repeat and variable condition as the previous experiment. Because there is no difference in the condition for the two groups during the training phase, we selected the target sequence which was disrupted. More precisely, we looked at variable condition when disruptions were put in place for variability and repeat condition when extinction were put in place for repeat condition. Figure 18 and 19 introduce the U value during the training phase and extinction phase for the variable and repeat group. First, we can observe that the disruption phase seemed not to affect the level of variability compared to the training phase. Similarly to the previous experiment, we can observe a slight augmentation of variability in extinction when variations were previously reinforced and decrease of variability when repetition were previously reinforced. In order to look more closely the results of variations, we investigated the percentage of sequences used during the experiment.

Figure 20 depicts the percentage of sequence used in different condition for the different phases in the two groups. Considering the 27 possibilities, we looked at the percentage of sequence emitted in repeat condition for the training phase, we can observe less than 20% of the sequence possible were emitted. In the variable condition, the percentage of sequence reached 60%. Visually, variability slightly increased when variable sequence are extinguished. On the contrary, participants tend to emit the same sequence when repetitive behaviors are under extinction. Relatively to the training phase, non-contingent reinforcement seemed not to affect the degree of variability for both groups.

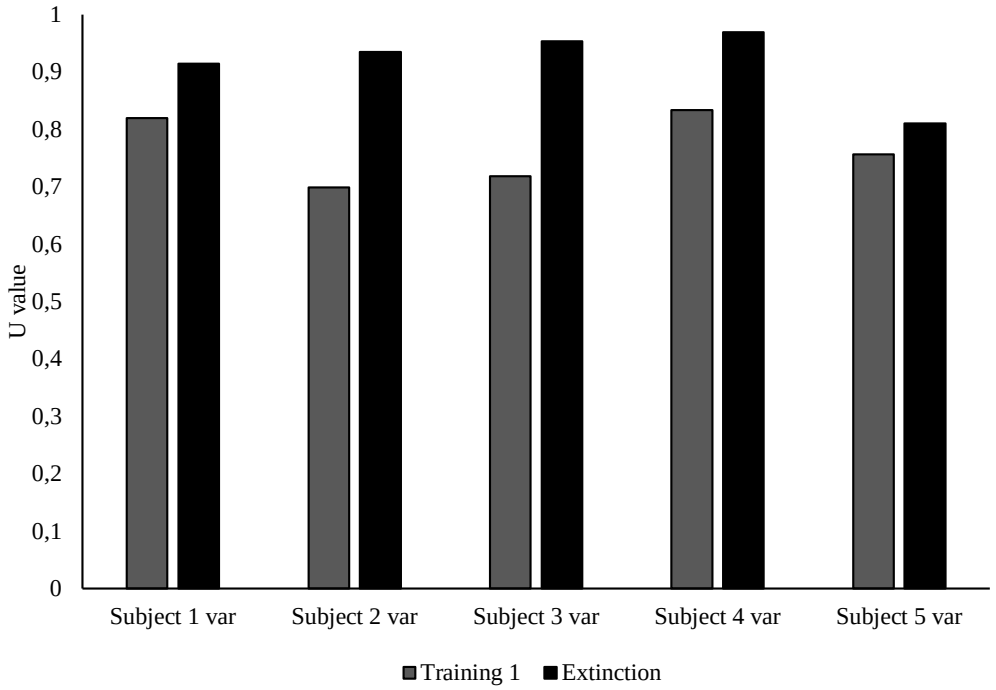



**Figure 18.** U value for each subjects of the variable group during the training and extinction phases

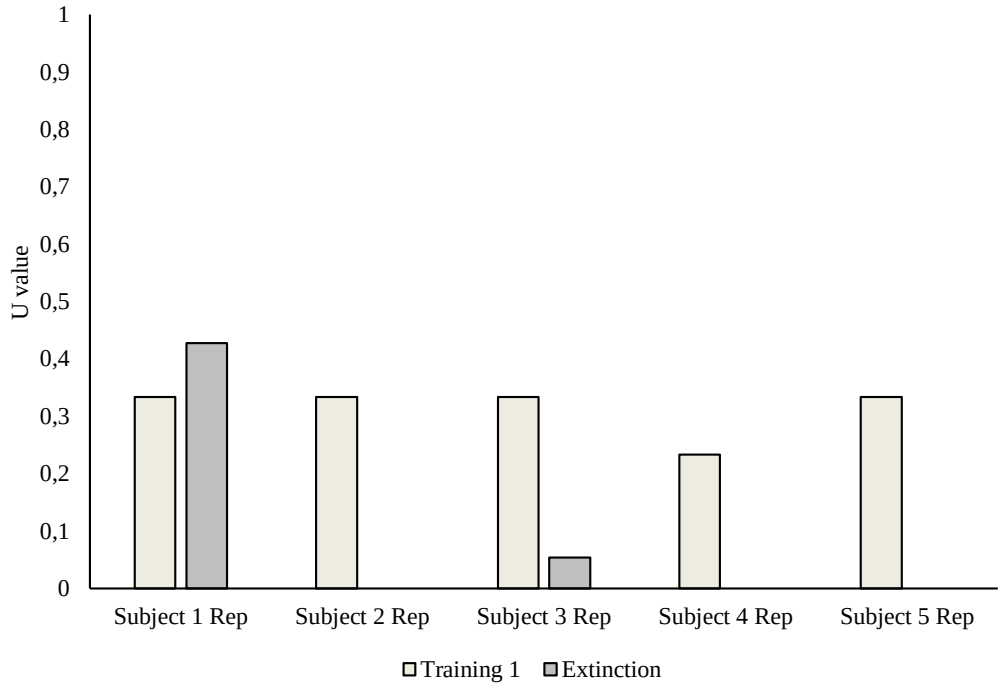



**Figure 19.** U value for each subjects of the repeat group during the training and extinction phases.

## 2.3.6 Discussion

Experiment 1 enabled us to assess the effect of disrupters on high levels of reinforcement rate when variable and repetitive sequences were trained. Due to the criteria used during the disruption phases, there was no convincing data when non-contingent reinforcement was put in place. The second experiment was carried out to further our analysis. In fact, we aimed at decreasing this level of reinforcement to assess its effect on the level of variability during the disruption phases. We used a new procedure in which participants had to emit 10 different sequences to get reinforced, and a repeat 10 schedule to reinforce repetitive sequences. When stability was reached in the two conditions, we introduced one first disrupter – extinction. This disruption consisted in no longer distributing reinforcement. After the first disruption, a second training phase was put in place followed by a disruption phase in the form of a non-contingent reinforcement. The second difference with the first experiment was the duration of the disruption phases. In the first experiment, participants had to stop to press keys for 20 seconds to end the disruption phase. Because participants were "stuck' in the extinction phase and did not respond in the VT phase, we set the disruption to 5 minutes whatever the participant did. Lastly, to produce more responses during the VT phase we increased the duration from a VT-5 seconds to a VT 15 seconds. Interestingly, the results of the experiment were similar to the previous experiment. We observed no significant changes between the training and the disruption phases for the two groups. These results might be explained by three variables. First, the contingency of reinforcement in the training phase. Depending on the errors at the beginning of the experiment, we can consider the training phase as a FR-10 schedule of reinforcement in which if no error is made, reinforcers were distributed every 10 sequences in each condition. Some results in experimental literature and in clinical settings suggest that behaviors which are maintained with a low rate of reinforcement tend to be resistant to extinction. Cohen (1998) suggested that resistance to change in extinction is related to the reinforcement rate. For instance, he found that a given behavior was more resistant to change after training in a VI-120 seconds schedule than in a VI-30 second schedule.

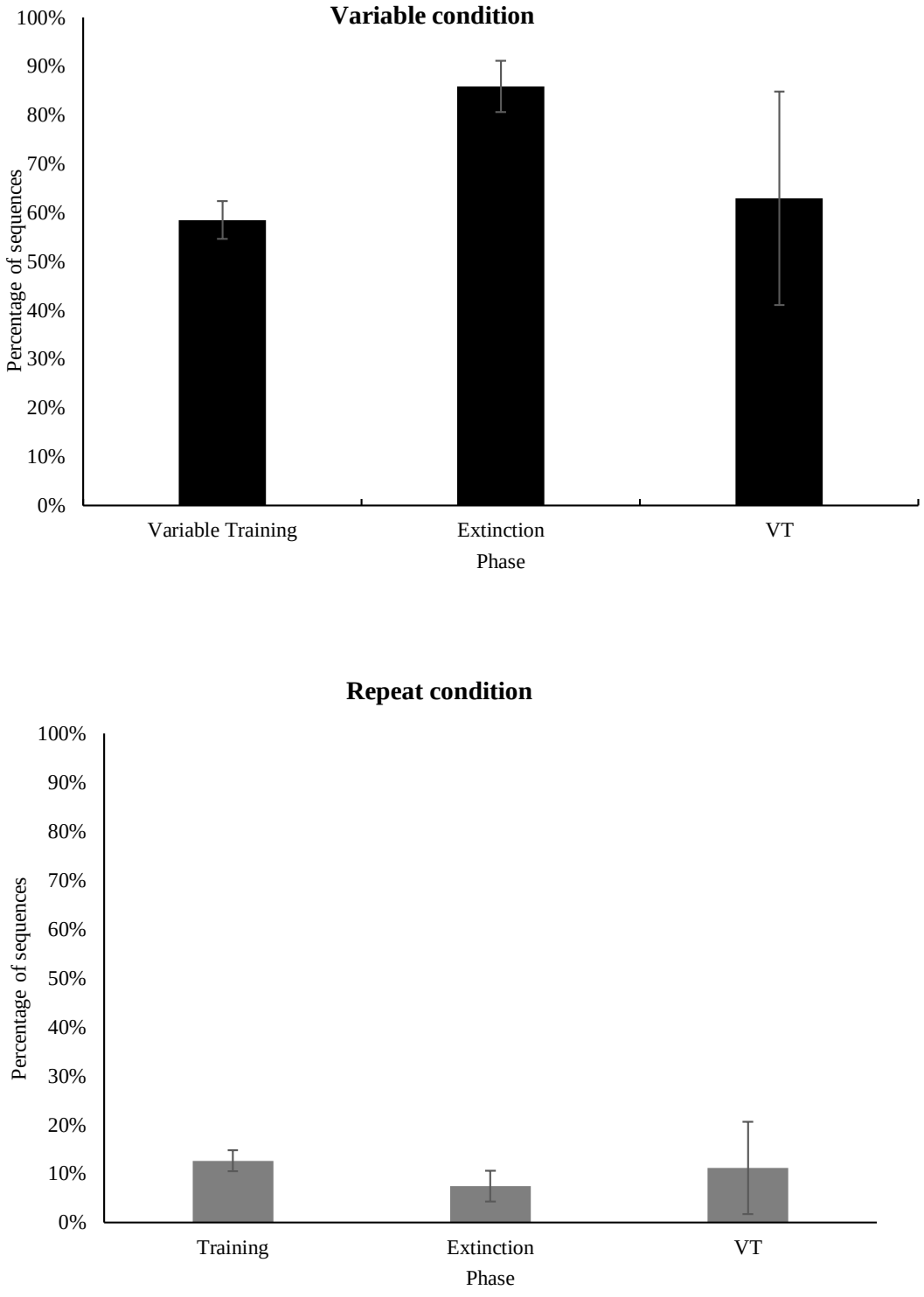



**Figure 20.** Percentage of sequences emitted in the two groups for the repeat and variable condition

These findings are related to clinical settings in which we observe that problem behaviors which are maintained by a low rate or intermittent reinforcement are likely to be more resistant to change than behaviors which are maintained in a CRF schedule of reinforcement.

The second parameter which might affect the resistance to change in extinction was in the nature of the task used for the participant. As a reminder, we used a simple interface with 3 disks and a central disk. Participants had to emit either variable or repetitive sequences to reduce time. The reduction of duration was used as a reinforcer. At the end of each experiment, the experimenter interviewed the participant. Most participants revealed the tedious aspect of the task. In fact, our procedure tends to create repetitive patterns of behaviors, once participants find how to emit 10 different consecutive sequences, they merely have to emit the same pattern over and over. As a reminder, the experiment offers 27 possibilities. In the variable component, only 2 of the participants emitted the totality of the sequences, whereas in the repetitive condition, no participant emitted more than 10 percent of the possibilities.

These two first studies were similar to the investigation in human carried out by Souza, Abreu-Rodrigues and Boumann (2010). The authors investigated behavioral variability during transitions from non-operant contingencies (no reinforcement, independent reinforcement) to operant contingencies. In a first experiment the authors compared learned variable and repeat response when no reinforcement occurs. This contingency consisted of no distribution reinforcement (i.e. contingently to the emission of a behavior). They found that exposition to a non-reinforcement contingency alters the acquisition of variable sequence but not repetition. These results are similar to those found in the experiment 1 and 2 of this thesis. We can observe that history of reinforcement has a direct influence on the operant variability and repetition. In fact, results suggests that stability of a given pattern is directly dependent to the contingency (independently to the structure of the pattern of responses). However, when comparing the two previous studies, we can observe the same tendency to repeat the same functional pattern. Some studies suggest that despite its advantages, this way to create variability could induce stereotypical patterns of behaviors. In fact, participants employed strategic stereotypical responding to obtain points (Lee & Sturmey, 2003; Neuringer & Jensen, 2013). For instance we could observe that participants start their first sequences using the same letter (e.g. AAA, AAZ, AAE etc...). In this case we can observe a repetitive pattern in the first three sequences. However, more the lag and the sequence are long, less efficient is that strategy. The previous experiments used a lag and a similar procedure to create variability, it showed that the level of variability can be increased from training to the extinction phase. Indeed, we observed an increase of both U value and, parallel observe same tendency in the percentage of sequences emitted in the variable training and then in extinction. A post analysis of results led us to the

following observation: there were, in both groups, sequences which were never emitted. One can argue that the criterion used by the lag procedure reduced the number of possibilities that one participant could emit. However, we succeeded in reinforcing the level of variability up to 90% of the total of possible sequences. More than 24 of the total sequences were emitted in the variable condition, but there were still approximately 3 sequences which were never emitted for 3 of the 5 participants. Considering the free operant method aspect of this experiment, these sequences were not defined for the different participants.

In the next experiment we addressed the following question: What about these sequences which are not emitted? Considering that extinction increases the level of trained variability, we aimed at assessing if there was a possible selection of the rare responses when variability was trained with a lag procedure. What is more, considering the stereotyped aspect of the patterns induced in the repeat component, we can ask ourselves if selection is possible even when variability is very low. The second study of this thesis aimed at answering these questions.

# 3. Chapter 3: Repetition and Variability in the Acquisition of Rare Response

## 3.1 Experiment 3.1

The second part of this thesis aimed at studying the relation between operant variability and response selection process. Theoretically, selection process and variations are an important part of operant conditioning, in practice, it has been mostly left out, at least with humans. However, previous experiments demonstrated that both variability and repetition can be shaped by environmental contingencies, the resistance to change of this continuum is directly dependent to the reinforcement contingencies. We observed in the experiment 1 and 2 that high degree of variability implied that participant emitted many different sequences, and that repetition implied the emission of one main sequence. More precisely, this first computer task offered 27 sequences possible, despite the high level of variability in the variable condition, there were still at least 10% of sequences which were never emitted. Considering these sequences as rare, we asked how operant variability and repetition could be implied in the acquisition of such sequences.

Operant variability and the acquisition of rare response has been investigated mainly with animals (Neuringer, 2002) but results with humans seem to be ambiguous. Indeed, first, experimental data suggest that reinforced variability interferes with the acquisition of rare responses (Doolan & Bizo, 2013; Maes & Van Der Goot, 2006). Second, observation of psychopathologies like ASD, Depression or ADHD seems to demonstrate that variability is crucial in learning process (Van Geert & Van Djik, 2002). Experimentally, the two main studies on the topic failed to demonstrate that operant variability facilitates the acquisition of rare responses with humans (Doolan & Bizo, 2013; Maes & Van der Goot, 2006). In a computer game, the authors replicated an experiment by Neuringer (2000) in which they concurrently reinforced variability and low probable responses. They found that instead of facilitating the acquisition, using concurrent reinforcement of variability interferes with the selection of rare responses. Considering the results of these experiments, we proposed a different perspective to study the relation between variability and rare response selection. Instead of reinforcing

concurrently both variability and a target response, we proposed a two-steps experiment in which, first variability or repetition is shaped, and secondly, a given rare response have to be learnt. In literature, authors have used three different terms to label a response which appears at a very low frequence: difficult, complex response and rare. Because to our opinion the difficulty and the complexity of a response are two terms which are hardly operationalized, we focused on the rarity of response. In our experiment rarety is defined based on the occurrence's probability of a response (Neuringer, 2002; Machado, 1992). Actually, less probable is the occurrence of a target response, the more it is considered to be rare. We can observe in literature similar definition of rarity, for instance Neuringer (1993) designed an experiment which aimed at studying "reinforced variation and selection" with rats. Target responses were sequence of four Left (L) and Right (R) lever press. The author used a lag procedure to reinforce variability and defined three level of response rarity and complexity. This degree was based on the baseline in which we observed that some sequences tended to be emitted more frequently than others. Neuringer (1993) found that the more a sequence is rare, the more operant variability facilitates its acquisition. As previously described, same results have been found in several animal experiments (Neuringer, 1993; Neuringer, Deiss, & Olson, 2000). In Human studies, authors used the term "difficult" as an interchangeable term for rarity. Indeed, in these experiments, a response is defined as difficult if it occurs at a very low level. For instance in an experiment in which subject had to emit sequences in a computer game, Maes & Van Der Goot (2006) defined the difficulty of the response on its relative frequency. They assumed that, because this response was relatively less emitted compared to other, it could be considered as difficult. However, the authors discussed the definition of difficulty. In fact one response can be emitted at a low frequency and not be difficult. Someone can ask what does make a response difficult. It seems that there several parameters must be taken into account and not only the frequency of a response (Grant, Berg & Esta, 1948). For instance, these parameters can be the cost of response, physical constraint, the presence or lack of the skill in the behavioral repertoire etc… Because of the different critics of the term difficult and because there is no fulfil definition of difficulty, we had rather used the term rarity in our studies. Based on the previous experiments we proposed to use the "var procedure" to produce both repetition and variable sequences. Actually, in the previous experiment we observed that this procedure could induce a high level of variability. In the same way, using a procedure in which *n* same responses have to be emitted to get reinforced, we produced a high level of stereotyped responses. The purpose of the present study is to bring both new data and procedures to compare the implication of behavioral

variability and repetition in the acquisition of rare response. Our question is similar to the aforementioned studies (Neuringer et al., 2000; Maes & Van der Goot, 2006; Bizo & Doolan, 2013) in that we ask to what extent reinforced variability facilitates the acquisition of rare target sequences. To shed light on this issue, we propose to compare the effect of behavioral variability to repetitive behavior in the acquisition of rare response. Instead of concurrently reinforcing variability or repetition, we arrange a first phase in which we trained either variable or repetitive responses. In a second phase in which we could observe the effect of such a contingency on the acquisition of a difficult sequence. We should observe two outcomes: in phase 1, a higher level of behavioral variability for the variable group than the others and, in phase 2, a better performance for participants who were trained to emit variable behaviors. In contrast, participants in the repetition group should be less efficient in the acquisition of the difficult target sequences.

### 3.1.1 Method

Twenty undergraduate students of the University of Lille were recruited, ten males and ten females, aged 18 to 30. An information letter was sent by mail before the day of the experiment. All students signed a consent form prior to the experiment.

### 3.1.2 Apparatus

The experiment was conducted in an experimental room in the SCALab laboratory at the University of Lille. We used a computer with Windows 2000 software and programmed the experiment on Matlab®, using the psychophysics Toolbox extension (Brainard, 1997; Pelli, 1997). Participants sat on a chair facing the computer; to enter the sequences, they had to use the “A”, “Z”, “E” keys on the computer keyboard. The letter corresponding to the three keys were also displayed on the screen computer in three blue disks of 4 cm diameter. When the participant pressed a key on the keyboard, the corresponding letter lighted up for 0.5 second along with a tone for 0.5 second. Correct sequences were reinforced by incrementing a counter in the upper center of the screen. Any wrong sequence was followed by a full grey screen for 2 seconds accompanied by a tone which lasted 0.5 second and no point was added.

## 3.1.3 Procedure

The following instruction was given to the participants (translated from French):

"*Thank you for your participation. You will play a computer game in which you have to find a way to earn the maximum amount of points by doing sequences on the A, Z, E keys of this computer keyboard."*

Once the instruction was given, the experimenter asked the participant if he had question and invited him to look at the computer. At the beginning, a black square on the screen appeared with the sentence (translated from French) "press on the Z key to start." displayed on the center of the screen. After one pression on the "Z" key, the three "A", "Z", "E" letters appeared. The experiment was divided into two phases. The first one consisted in training either variable, repetitive or no specific sequences. The second phase was divided into three sub-phases of five minutes, during which the participant had to learn a specific rare target sequence.

**Phase 1: Training Repetitive, Variable or no Specific Response**

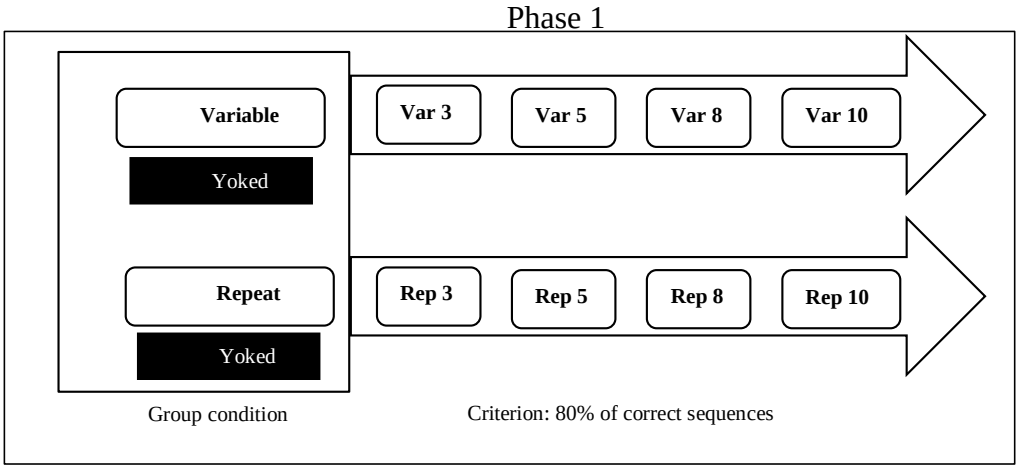



**Figure 21.** Description of the first phase of the experiment. Participants were trained to emit sequences depending on their group condition (variable, repetition, yoked variable and yoked repetition).

This phase lasted 30 minutes, the twenty participants were randomly assigned to one of the four groups (figure 21). In the variable group, we aimed at increasing behavioral variability. We used the var procedure described in the experiment 2. In order to shape behavioral variations, we progressively increased the length of the var contingency from a var 3 to a var

10 (Var 3, 5, 8, 10). For example, in a var 3, subject had to emit three different sequences to earn one point. When the participant reached a criterion of 80% of correct sequences during the ten last trials the current var contingency shift to the next.

The repetition group aimed at increasing repetitive sequences. We used a procedure similar to the var condition but instead of emitting different sequences, the subject had to emit same *n* sequences to obtain reinforcement. For instance, in a repetition criterion 3, subject had to emit three identical sequences to earn a point (Neuringer, 1992). We used for this condition the same criterion as in the variable group to shape repetition (rep 3, 5, 8, 10). In order to compare the effect of the contingencies and the reinforcers distribution, we put in place two control conditions (i.e. yoked variable and yoked repetition). In these conditions no specific contingency was set up except that the distribution of points was determined by the variable and repetition groups, respectively. Each point distributed in an experimental group was automatically distributed in the yoked group with the only constraint that the subject emitted sequences of three responses. These groups enabled to compare the effect of the experimental and control contingencies on the acquisition of target sequences in the phase 2. For all groups, at the end of the 30 minutes, a message appeared in the center of the screen with the sentence (translated) “Thank you, now the second phase will start”.

**Phase 2: Learning Rare Target Sequences**

This phase included three 5-minute sub-phases (Figure 22). For each sub-phase one rare target sequence had to be learnt. At the end of the five minutes, another sub-phase began with a new rare target sequence. The change of the rare target sequence between the sub-phases was not signaled. The rarety of the sequences was based on two criteria, either the sequence was never emitted or it was emitted less than 3% of the time in the first phase. During the sub-phases, points were distributed immediately after the emission of the correct sequence and non-target sequences were never reinforced. Phase 2 ended after the three five-minute sub-phases, then a message appeared in the center of the screen with the sentence (translated) “The experiment is over, thank you for your participation! You earned N points”.

Phase 2

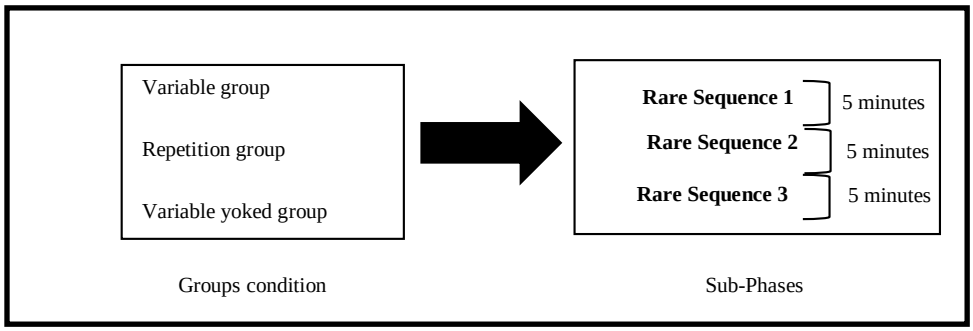



**Figure 22.** Description of the second phase of the experiment. All groups had to emit three rare target sequences during three 5min trial blocks**.**

## 3.1.4 Dependent variables

Three measures were used in this experiment. First, the U value, an indicator that enables to measure the degree of unpredictability and the distribution of the different sequences (Neuringer, 2000; Maes & Van der groot, 2006; Doolan & Bizo, 2013). We used the U value in the phase 1 to measure the level of variability in the four different groups. U value was calculated based on the 30 last sequences.

In the phase 2 we measured the mean percentage of correct sequences for each sub-phase. Lastly we measured in the three sub-phases the overall proportion of rare target sequence for each condition. For each measure, we also individually observed data to study the different simple effects in action.

## 3.1.5 Results

**U value**

Figure 23 plots the U value for five subjects in the Variable group. We can observe that the Var 3 contingency we have already a high level of variability (i.e. U value is between 0.6 and 0.76). At the end of the first phase U value is above 0.97 for two subjects and between 0.85 and 0.88 for the three others. Figure 24 plots the U value for five subjects in the Yoked Variable group. We can observe high fluctuation in data for every subjects. Compared to experimental group, the U value did not increase from the Var 3 contingency to the Var 10 contingency.

Figure 25 plots the U value for each subjects in the Repeat group. We can notice that U value decreases for every subjects from the Repeat 3 contingency to the repeat 10. At the end of this phase, every subjects emitted the same pattern of sequence. Figure 26 plots the U value for each subject in the Yoked Repeat group. Globally we can observe that contrary to the experimental phase none subject reached a 0 U value. Now we can examine the mean of the u-value in the four conditions (variable group, repetition, yoked repetition and yoked variable) for the different criteria (3, 5, 8 and 10). First we can visually observe a higher level of variability in the variable group compared to others. Second, the level of variability seems to increase in the variable group, decrease in repetition group and stay at the same level in the two yoked groups.

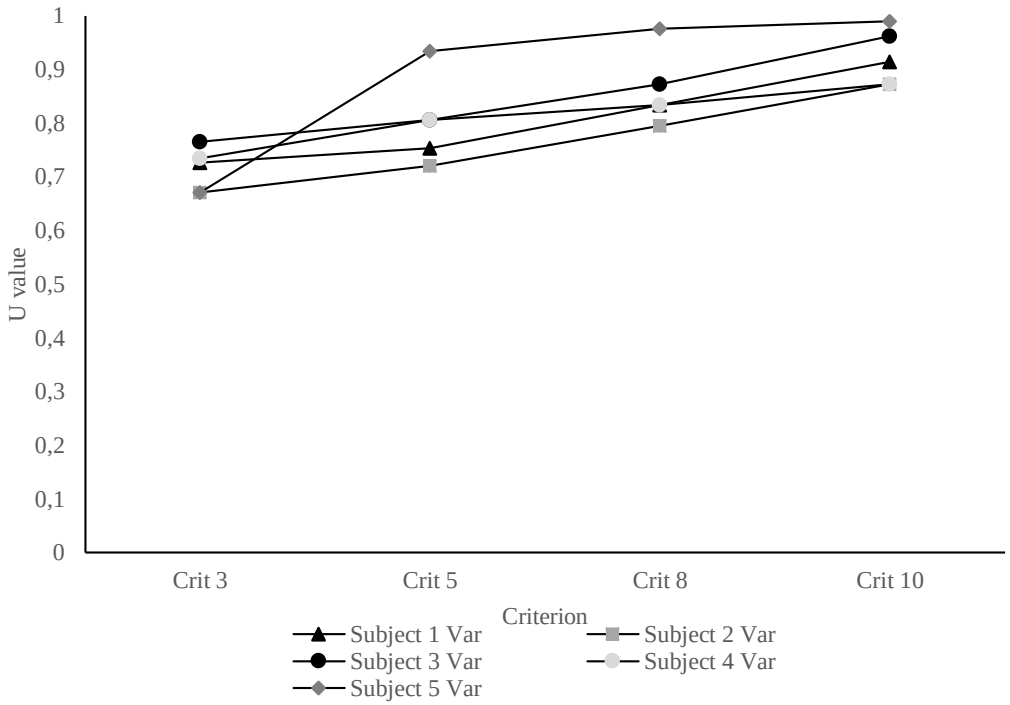



**Figure 23** U value for each subject in the Variable group

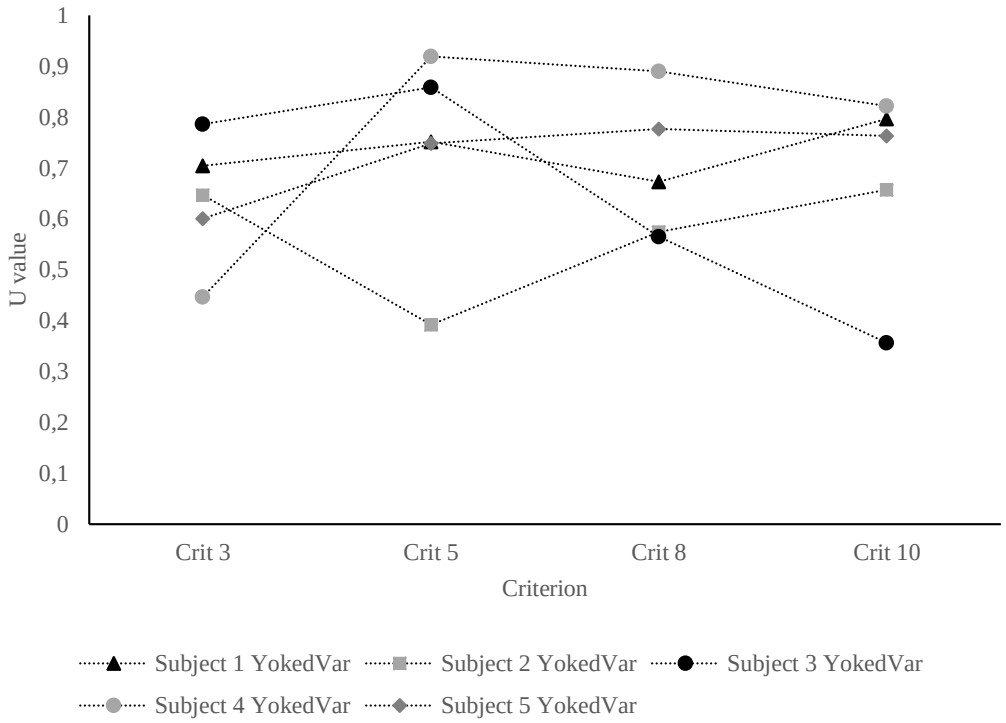



**Figure 24:** U value for each subject in the Yoked Variable group

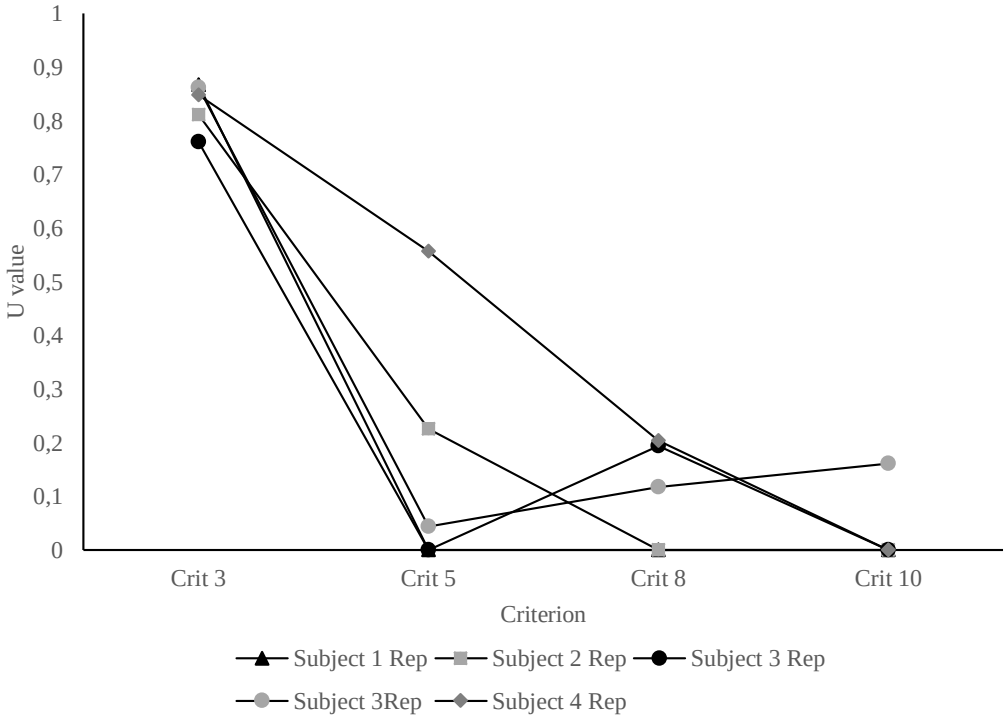



**Figure 25:** U value for each subject in the Repeat group

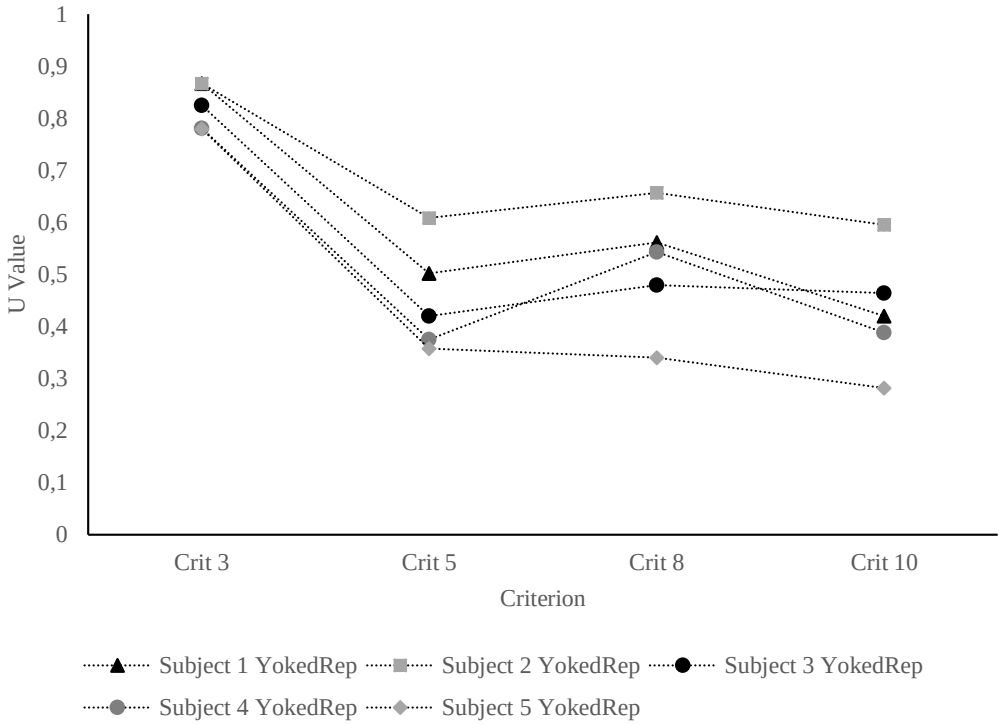



**Figure 26:** U value for each subject in the Yoked Repeat group

These results show that we succeeded to train high variable behaviors in the variable group and highly repetitive behaviors in the repetition group. The difference in the yoked repetition is due to the sharp drop of the U value between the criteria 1 and 2. Otherwise we don't observed difference for the u-value. Figure 27 plots the overall reinforcement rate (per minute) for all groups in the phase 1. Because of the length of the var contingency or repeat criteria in experimental groups we can observe a low rate of reinforcement. The student's test analysis of the overall reinforcement rate between the experimental repeat and variable group shows no difference $t(1, 4) = 2.77$, $p<0.05$.

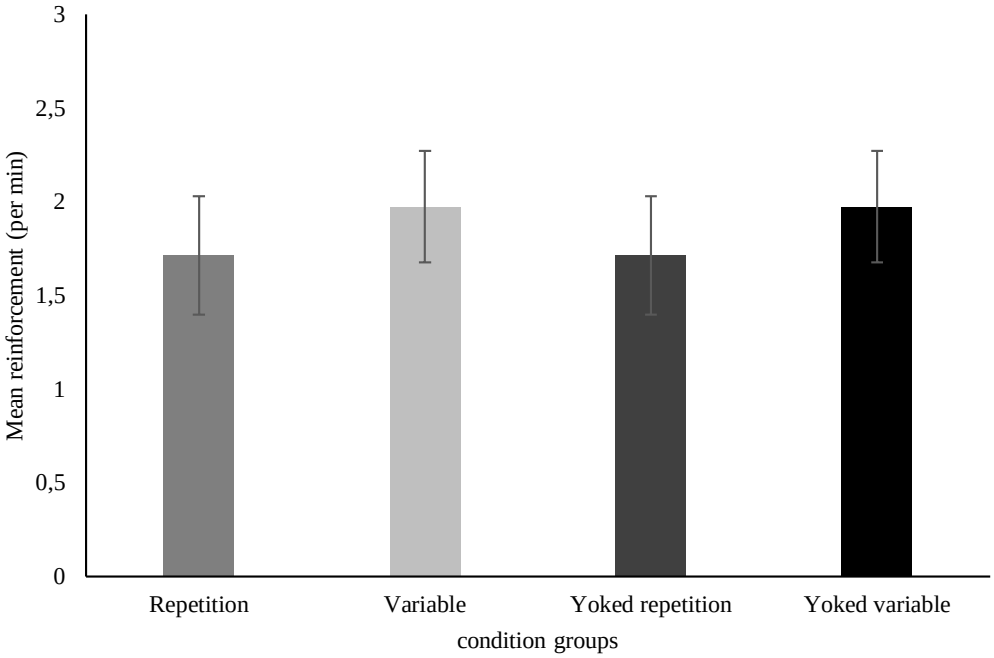



**Figure 27:** Overall reinforcement rate (per minute) for the phase 1

### Proportion of Correct Sequences

Figure 28 plots the percentage of correct responses for five subjects in the variable condition. For the sub-phase 1, results show that no subject emitted the correct sequence during the first block. In the fifth block, three of the five subjects emitted the correct sequence. For the sub-phase 2, during the first block, three of the five subjects emitted less than 30% of the time the correct sequence. At the end, all subject emitted the correct sequence. Lastly, for the last sub-phase, only one subject emitted the correct sequence in the first block and four of them at the end of the last block.

Figure 29 plots the percentage of correct responses for five subjects in the Yoked variable condition. For the sub-phase 1, compared to the variable condition, we can observe that one subject emitted 30% of the time the correct sequence, at the end of this fifth block, only one subject emitted more than 80% of correct sequence. For the sub-phase 2, we can observe that none of subjects emitted the correct sequence during the first trial block. At the fifth block, only one subject emitted more than 80% of correct sequence. Interestedly, it was the same subject as in the previous sub-phase. Lastly, for the sub-phase 3, we can observe that none of

the subjects emitted the correct sequence during the first block. However, two subjects emitted the correct sequence more than 80% of the time and two never emitted it in the last block.

Figure 30 plots the percentage of correct response for five subjects in the Repeat condition. For the sub-phase 1, during the first 60s trial block, only one subject emitted the correct sequence. At the end, during the fifth block, none subject exceeded 50% of correct sequence. For the second sub-phase, we can observe an increase for three subjects. Only one subject never emitted the correct sequence. Lastly, for the sub-phase 3, we can observe a slight increase in the performance from the first block to the last one for four of the five subjects. At the end, none of the subjects emitted more than 50% of the correct sequences.

Figure 31 plots the percentage of correct sequence for 5 subjects in the Yoked Repeat condition. We can observe that results are similar to the Yoked Variable condition. First, for the sub-phase 1, we can observe that only one subject mastered more than 50% of correct sequence from the first trials block to the last one. For the sub-phase 2, there is no increase in the emission of the correct sequence for none subject. We can observe that one subject emitted from the beginning of the sub-phase the correct sequence at 50%. For the sub-phase 3, there was an increase for three of the five subjects.

Figure 32 summarizes the previous results for each condition and for the 3 sub-phases. For the sub-phase 1, we observe that only the variable group emitted more than 50% of correct sequences at the end of the five blocks. For the sub-phase 2, similarly to the previous one, variable group shows the greatest improve from 30 to 80% of correct sequences. Similar results are observed for the sub-phase 3. However, for this sub-phase, we can notice an improvement in the performance for the three other groups even if it was lower than in the variable group.

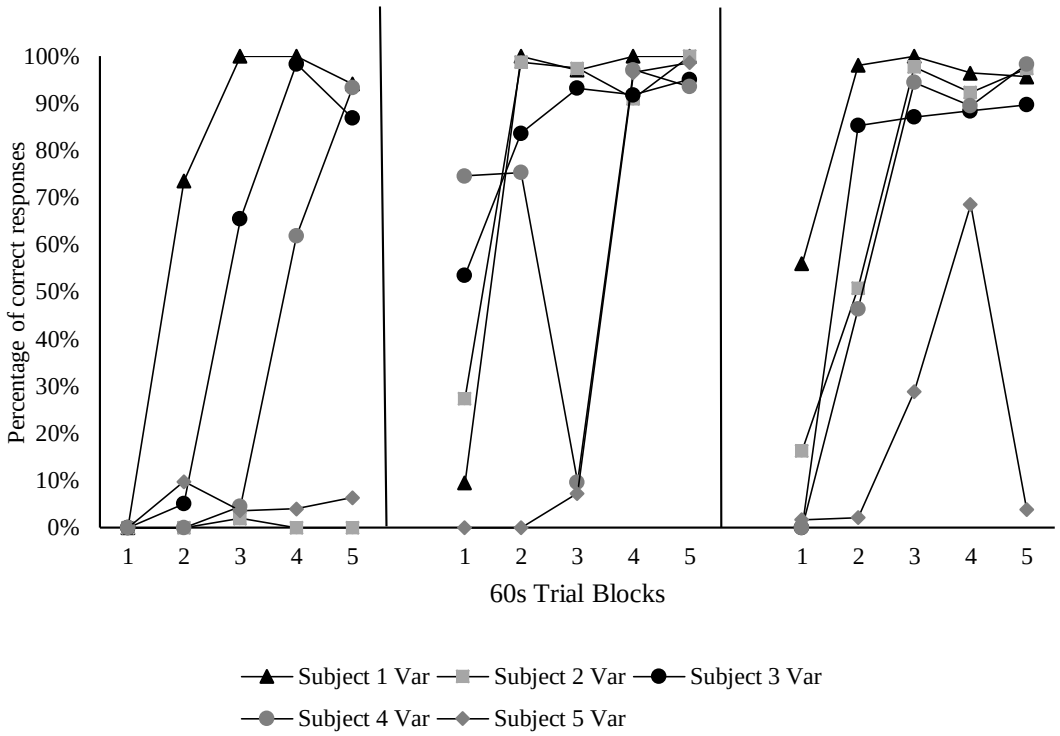



**Figure 28:** Learning phase in 3 trial blocks for 5 subjects in the variable group

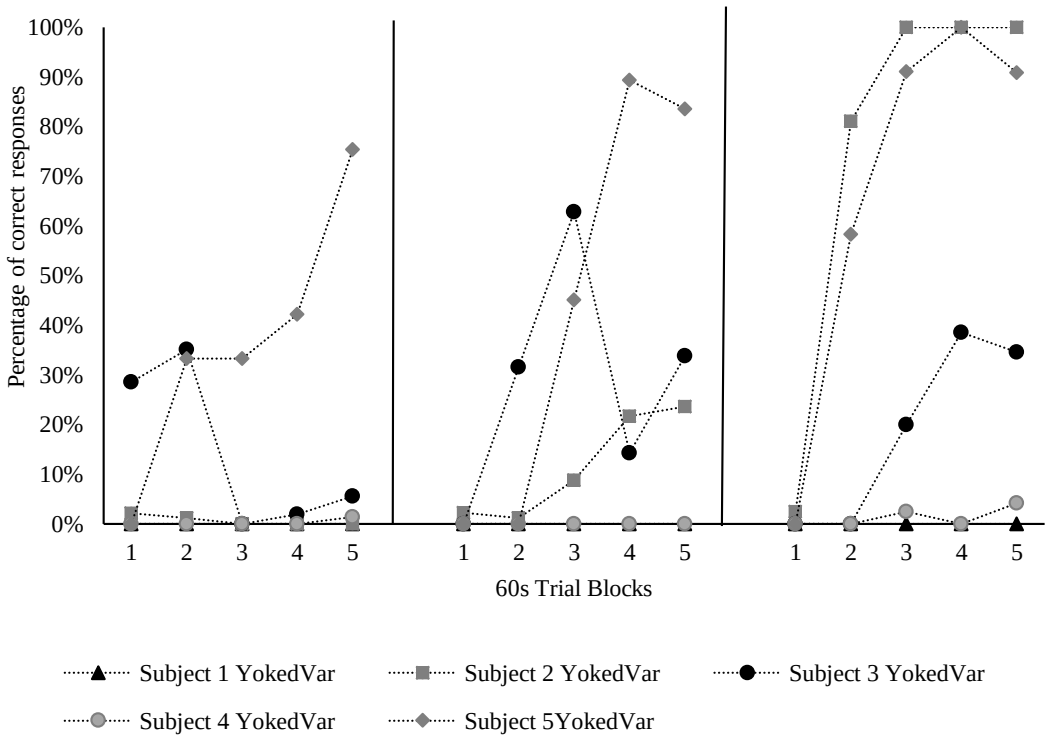



**Figure 29:** Learning phase in 3 trial blocks for 5 subjects in the Yoked Variable group

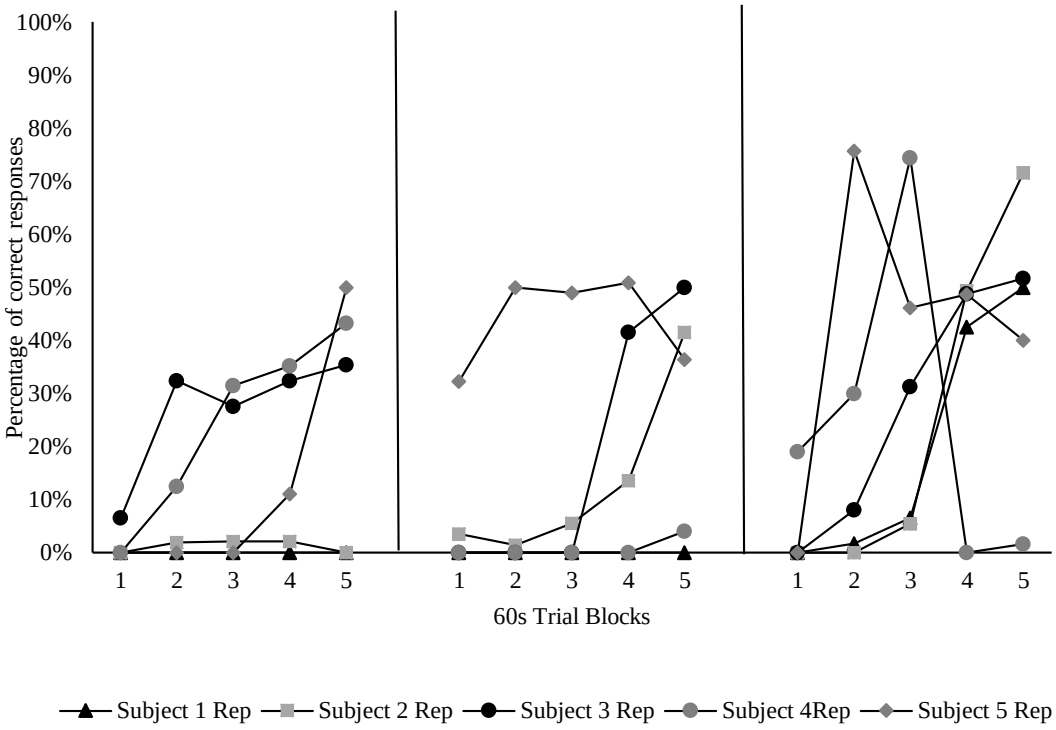



**Figure 30:** Learning phase in 3 trial blocks for 5 subjects in the Repeat group

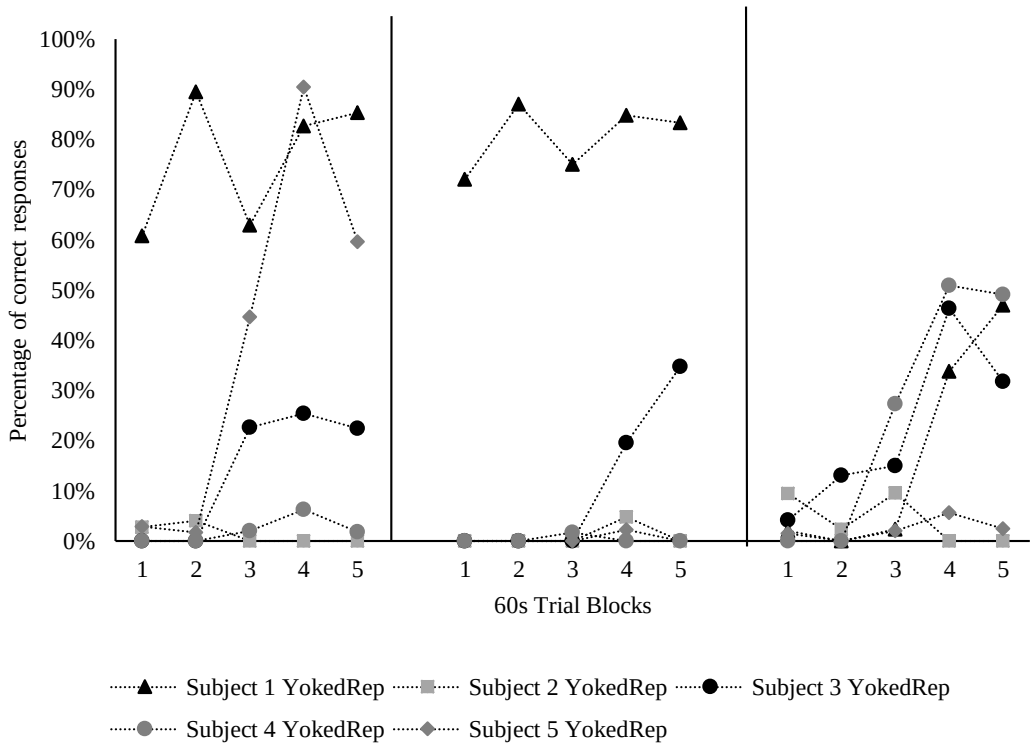



**Figure 31:** Learning phase in 3 trial blocks for 5 subjects in the Yoked Repeat group

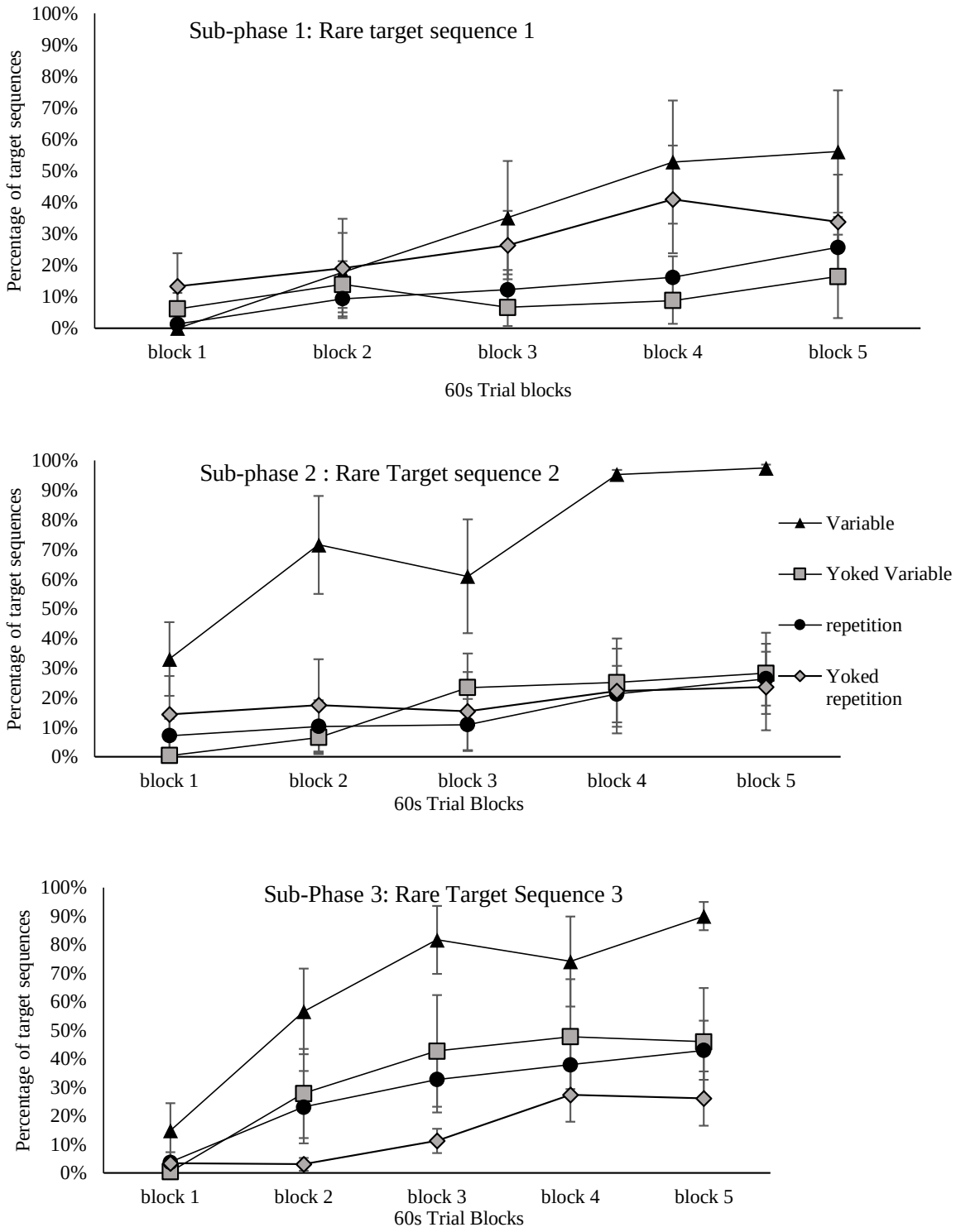



**Figure 32:** Mean percentage of correct responses for each condition group across trial blocks

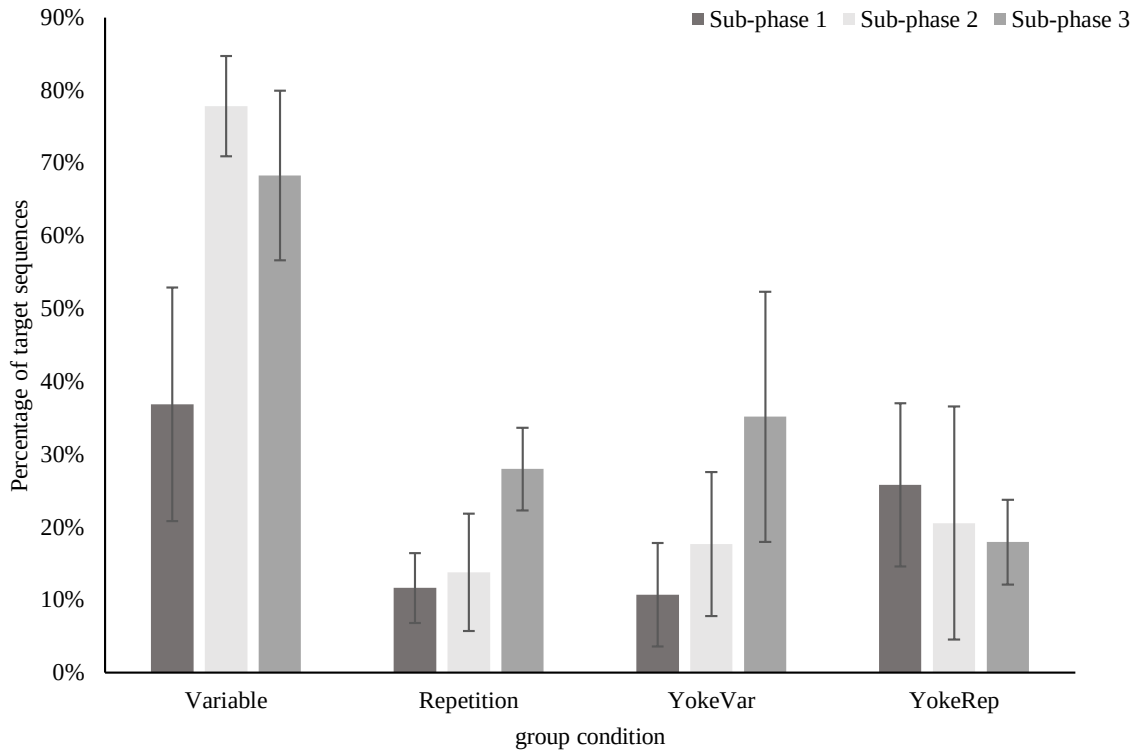



**Figure 33:** Mean percentage of correct sequences for each group condition for the 3 targeted rare sequences

Figure 33 consisted in studying the overall mean proportion of correct sequences for each condition for the 3 targeted rare sequences. We can visually observe a greater proportion of correct responses in the variable group for each block of rare sequences. These data suggest that based on the first phase, the group which was more efficient in the learning of correct sequences was the variable group.

## 3.1.6 Discussion

We aimed at comparing how training variable and repetitive behaviors influences the acquisition of rare target sequences on a computer game. The first phase of the experiment consisted in training either repetitive, variable or no specific behaviors. Participants were required to emit sequences of three keys on a computer. Four group conditions were created. In the variable group we increased the level of behavioral variability by increasing the length of a var contingency schedule (var 3, 5, 8, 10). In the repetition group, we shaped repetitive behaviors by modifying the length of the repetition criterion (criterion 3, 5, 8, 10). Lastly, obtained reinforcement in the two yoked groups was determined by the experimental ones. The

level of variability was measured by the use of U value, an indicator which enables to assess the degree of predictability of behaviors (Page & Neuringer, 1985; Barba, 2012). Two hypotheses have been raised. First, we assumed that the U value should decrease in the repetition group, increase in the variable group and stay at a relatively same level in the two yoked groups. Secondly, we should observe a higher level of U value in the variable group compared to the others. Results have shown that U value decreased when reinforcement was provided only for repetitive patterns of behaviors but increased when reinforcement was provided for variable sequences. However, the experiment started with a high level of variability, which prevents to conclude to a significant increase of the U value in the variable group. This level of variability at the beginning of the experiment can be explained with the different criteria used to create variability. Actually we shaped variability using a var contingency in which participants had to emit at least three different sequences or three same sequences to get reinforced. This window of criterion might put behaviors on extinction, which in turn may induce some variability. Despite this high level of variability, we can conclude that variations are controlled by the schedule because of the relative increase of variability in the variable group and the high decrease of variability in the repetitive one. Moreover, despite a decrease between the criterion 3 and 5, we can observe that variability stayed at a relative same level for the two controlled group. The absence of contingency may induce a certain level of behavioral variation. Interestingly, we observed the apparition of superstitious behaviors in both yoked groups. At the end of the experiment, when they were asked to give oral feedback about what they had experienced, most of participants of these groups mentioned different rules. These superstitious behaviors have been studied in literature in the absence of direct contingency between a behavior and the consequence (Skinner, 1963; Miller & Neuringer, 2000).

The second phase consisted in reinforcing three rare sequences during three sub-phases of five minutes. We hypothesized that training variable and repetitive behaviors should impact differently the acquisition of rare target sequences. It is important to notice that the three sequences are considered to be equally rare. Two observations can be emphasized. First, participants of variable group had generally the greatest proportion of correct responses for the three rare target sequences, and they were the only ones who performed more than 50% of correct sequences. Secondly, we can ask to what extent participant in the repetitive and yoked group would be able to learn the rare sequences if there were more trials.

Results of the current study support the findings in the animal literature (Neuringer et al., 2000) but are dissimilar to those in human experiments (Maes & Van Der Goot, 2006; Doolan & Bizo, 2013). With the present study we aimed at providing another way to assess behavioral variability with humans. Instead of concurrently reinforcing rare target sequences and variability, we used a training phase in which we trained variable and repetitive behaviors and then we compared the experimental and the control groups in the acquisition of rare target sequences. Our results support the hypothesis that behavioral variability facilitates learning. One limitation of our study can be found in the definition of the rarey of the sequence. As presented in the previous studies (Maes & Van Der Goot, 2006; Doolan & Bizo, 2013), rarety of a task is often associated with the probability to emit it. The fact is that if a behavior has never been emitted, it does not necessarily mean that it is difficult to emit. Such assertion just implies the fact that the current behavioral repertoire of the organism does not enable him to emit the rare behavior. In operant learning, does the acquisition of a new behavior is considered to be difficult?

Optimum level of behavioral variability is an important feature for operant learning (Skinner, 1938; Palmer & Donahoe, 1992). It contributes to the development of cognitive stages, complex motor skills, creativity and problem solving (Bancroft, 2012; Novak & Pelaez, 2014). Other studies have demonstrated that training variable behaviors may affect performance with rats (Grunow & Neuringer, 2002). In a first step, authors reinforced different level of variability (low, intermediate level and high variability) among four groups of rats. Behavioral variability was first under a continual reinforcement schedule, which was thereafter thinned to a variable interval schedule of reinforcement. In the second step, the authors compared all groups in the acquisition of a difficult target sequence. The relative frequency of the difficult target sequence was higher in the group that had been previously reinforced for high variable behaviors. In other words, this experiment demonstrated that, with rats, behavioral variability facilitates learning.

The importance of behavioral variability in operant learning can be illustrated in psychopathologies like ASD or attention deficit hyperactivity disorder (ADHD). The question of reinforcement of behavioral variability with people has been raised for the last decades. Miller and Neuringer (2000) have demonstrated that variability could be increased among people with ASD, in an experiment in which adolescents with ASD and control adults had to

emit variable sequences. In a first step, reinforcement was provided independently of variability. The authors observed that participants with ASD emitted patterns of sequences less variable than the control group. Secondly, reinforcement was provided for the emission of variable behaviors. Results showed that behavioral variability increased consistently in both groups. Like many others, the authors recommends to study the relation between operant variations and selection with human.

## 3.2 Experiment 3.2 (Pilot study)[1]

In the experiment 3.1 we demonstrated that reinforcing behavioral variations facilitates the acquisition of rare sequences of responses. In that experiment, we set up a computer game in which we induced different behavioral variations. This methodology for investigating behavioral variability is widespread in Human literature (Morgan & Neuringer, 1990; Machado, 1989; 1997; Neuringer & Huntley, 1992; Denney & Neuringer, 1998 etc…). In most of those experiments, variations are investigated on one dimension of responses (e.g. differentiation in sequence, inter-trial-response) (Neuringer, 2002). Despite its interest, this methodology is limited considering that variability is investigated on only one dimension of response in the same task (e.g pecking, pressing a lever press, key press etc…). In fact, when we observe behavioral changes in natural environment, variability is often present on many dimensions of behaviors. For instance if one emits ten times the same movement, variations will occur across duration of movement, their amplitude, magnitude etc… Investigating behavioral variation across classes of response may bring a better understanding in behavioral changes.

A different way to study operant variability was proposed by Holth (2012). In this experiment, rats were reinforced to emit variable responses on different operanda. This experiment is interesting considering that, the use of different operanda implies the emission of different response classes. During a first phase, the author reinforced four types of responses: right lever press, left lever press, wood lever press or nose poke on a photo cell. Reinforcement was delivered on a lag 3 contingency. Using this schedule of reinforcement, rats, alternated between the different operanda and every response produced reinforcement. In a second phase,

[1] This study is a pilot one, due to the deadline it contained only 3 participants. It aims at providing a different view for future experiments

the author introduced a new operandum, a chain, and shifted the lag schedule from a lag 3 to a lag 4. The author observed that after numerous sessions, rats emitted responses on all operanda even if the percentage of reinforced responses were lower than in the previous sessions. This experiment enabled to observe a different way to investigate behavioral variability.

The last study of this thesis is based on Holth's experiment (2012). It aimed at providing a different methodology to investigate behavioral variability. We add one variable in this investigation: different consequences (i.e. reinforcers) were associated to different degrees of variations. In this way, we used different consequences to reinforce behavioral variations across different operanda. Traditionally, experiments with animals mainly use food as a positive reinforcer, in human studies, points seem to be the most common reinforce. However, using points and positive feedbacks (Maes and Van der Goot, 2006; Doolan and Bizo, 2013) as reinforcers can be considered as different as using food. The effect of points or positive feedback are commons and may produce satiation quickly. During the 3 previous studies, we used points and diminution of time as reinforcers to control variability. Time reduction was a direct consequence and points were not associated with primary reinforce. In the second case, some investigations questioned the powerful aspect of points (Maes, 2006). However In this last pilot study, we aimed at producing different degrees of variability associated with different type of reinforcers (pictures, points associated with pleasant events). The aim of the experiment we designed was to have a different approach on operant behavioral variability with humans. Two questions were raised. First, using different operanda, how does reinforcing variability enable the development of responses with different topographies? Secondly, how may the use of qualitatively different reinforcers influences behavioral variations?

We designed a computer game in which participants had to respond on three different devices to obtain different consequences. These devices were a mouse, a keyboard, and a force transducer. We manipulated the relative frequency of response on each device. The consequences were either pictures from different categories (nude, landscape, funny pictures) or points, (participants were instructed that they could earn a cinema ticket or a soda if they reach 100 points). We used a reversal design which consisted of a baseline, an experimental phase and a second baseline (Byiers, Reichle & Symons, 2012). During the first baseline, neutral pictures were randomly distributed independently of participant responses. This phase aimed at assessing the relative frequency of response per device. During the experimental phase

reinforcers deliveries were dependent on the relative frequency of response on each device. During the second baseline we assessed changes in the relative frequency of response per device. During the first baseline we should observe a low response frequency on the force transducer relatively to the keyboard and the mouse. Using the different reinforcers associated with different level of relative frequency during the experimental phase should increase the probability of response on the force transducer. In the last baseline, we should observe more responses on the force transducer compared to the first one.

## 3.2.1 Method

Three undergraduate students of the University of Lille were recruited, two males and one female, aged 18 to 30. An information letter was sent by mail before the day of the experiment, all of them signed a consent forms prior the experiment.

## 3.2.2 Apparatus

**Devices and target behaviors**

The experiment was conducted in an experimental room in the SCALab laboratory at the University of Lille. We used a computer with Windows 2000 software and programmed the experiment on Matlab®, using the psychophysics Toolbox extension (Brainard, 1997; Pelli, 1997). Three devices were used in this experiment (see figure 34): a keyboard, a computer mouse and a force transducer. The first device was a basic computer mouse with two buttons and a scrowl wheel (which can also acts as a third button). Pressing the two buttons, the scrowl wheel or moving the mouse computer was recorded by the computer. The second device, a computer keyboard of 105 key. A press in an area of the keyboard were automatically recorded by the computer program. The last device was a force transducer which is a sensor converting an input mechanical force into an information signal. We observed that most participants of parallel experiments did not know what a force transducer is and how to use it. Based on these observations, we assumed that this device might be not used at the beginning of our experiment. Any press at any force on the top of the force transducer was automatically recorded by the computer program.

**Consequences**

Specific consequences were distributed in the different phases of the experiment. During the baseline, we used pictures from the Snodgrass database (Snodgrass & Vanderwart, 1980). These standardized black and white pictures represents are commonly used to assess memory and cognitive processes. There were picked in this experiment because of their "non-appetitive" aspect. During the baseline, there are considered to be neutral compared to other stimulus presented in the experimental phase.

For the experimental phase we picked consequences which were qualitatively differents. An evaluation of preference between the different stimuli were put in place prior the experiment. Their distribution depended on the relative frequency of response interval emitted on each device. First, pictures (nude men, Women, Landscape or Well Being) which were selected in advance by the participant. Each categories contained a set of 50 pictures. Pictures were directly screened after the emission of a correct response. Second, Tokens are used as reinforcers. These are delivered 10 at a time depending a relative frequency interval. When a total of 100 tokens is reached, the participant wins a ticket to the theatre or a drink. The participant cannot win more than 100 tokens (see table 3).




**Figure 34 :** operanda used during the Experiment**.**

## 3.2.3 Procedure

Participants sat in front of the computer and the different devices. No instruction were given except:

*In this experiment you can earn pictures from a specific category, 100 tokens to obtain a Soda and 100 tokens to obtain a Cinema Ticket.*

**Baseline**

The baseline aimed at assessing the relative frequency of response per device. We used "neutral" pictures from the Snodgrass data base. In order to avoid an extinction effect of the participant's behaviors and to maintain a certain amount of response rate, pictures were delivered on a VT 5 seconds during which pictures were distributed non-contingently to the emission of responses on an average of 5 seconds. This phase lasted for 5 minutes.

**Experimental phase**

This phase consisted in reinforcing the use of a device depending on its relative frequency. Based on the data gathered in the baseline phase, using a device could produce (or not) either pictures or points. In order to avoid the use of the same device, two consecutive presses on the same device were no followed with reinforcement. Each reinforcer were available at the same time. Based on the observation that there was at least 100 responses which were emitted during the baseline, a response which has never been emitted during baseline was directly reinforced with the reinforcer which has the highest qualitative value (e.g. Cinema ticket). Imagine the participant emitted 200 responses which were equally shared between the areas 1, 2, 3 and 4. Any press during the experimental phase in one of these three areas would inevitably lead to the distribution of a picture (which has the lowest qualitative value). In parallel, the press of the captor sensor would lead to the increment of the gauge to get the Cinema ticket. This phase lasted for 30 minutes

**Baseline 2**

This phase is identical to the first baseline. Neutral pictures were distributed on a VT 5s schedule of reinforcement.

## 3.2.4 Dependent variables

In this experiment, we used a single subject analysis. First, based on their relative frequency we analyzed the percentage of responses per device for the different phases. Second, we focused on the percentage of response on the force transducer. Because of the lack of participants in this pilot study, data analysis will be descriptive.

**Table 3:** Description of the different reinforcers (Pictures, tokens for drink, Tokens for Theater and the different contingencies related to their distribution

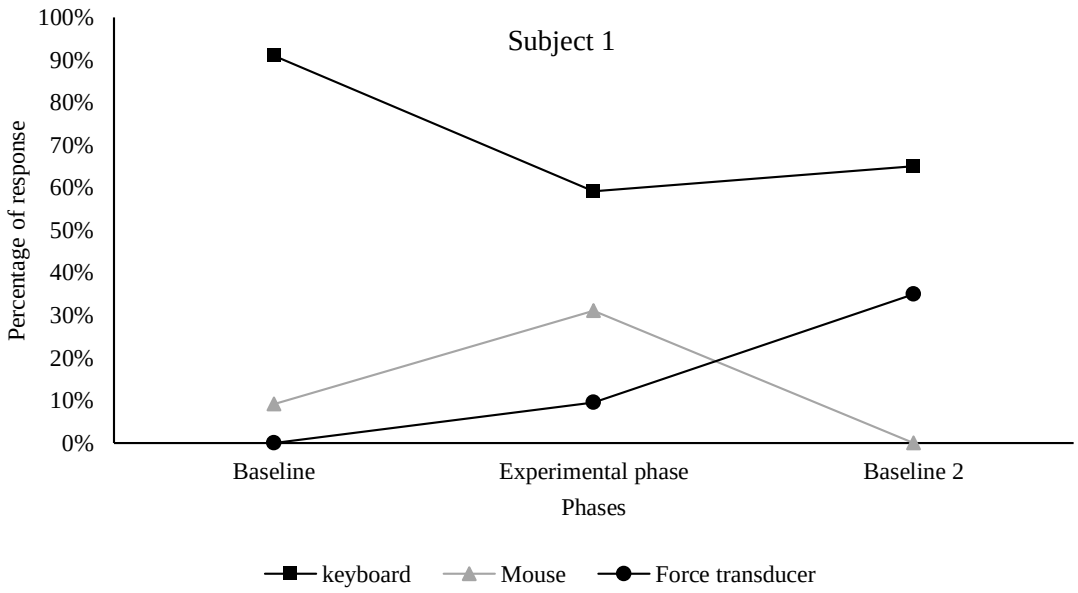
| Phase | Consequence | Contingency |
|---|---|---|
| Baseline 1 | Neutral pictures from Snodgrass database® | Variable Time schedule 5 seconds (VT5), reinforcement is delivered on an average of 5 seconds (independently of particpant's responses) |
| Experimental Phase | Reinforcers :<br>- Pictures<br>- Tokens for Drink<br>- Tokens for Theater | Depending on the relative frequency of response on each device:<br>- [0.15 ; 0.30]<br>- [0.05 ; 0.15]<br>- <0.05 |
| Baseline 2 | | VT 5s |

## 3.2.5 Results

Figure 35 shows the percentage of responses emitted on the keyboard, the mouse and the force transducer for the three participants. As we predicted, the force transducer was less used during the baseline for each participant. For every participant, the keyboard was the device on which we observe the most responses. Participant 1 emitted only 10% of his responses on the mouse and none on the force transducer. During the experimental phase we can observe that more than 10 % of response were emitted on the force transducer and 30% on the mouse. At the end of the experiment, during the baseline 2, participant 1stopped to emit response on the mouse and used the force transducer. Results of the participant 2 are very similar, he emitted 20% of his responses on the mouse and 3% on the force transducer. During the experimental phase we observe a relative increase in the percentage of responses on the force transducer and 30% on the mouse. At the end of the experiment, during the baseline 2, participant stopped to emit response on the mouse.

Finally, we observed similar results with the participant 3. At the beginning of the experiment few responses are emitted on mouse and force transducer. During the experimental phase we can observe an increase in the responses of these two devices. Most interestingly, at the end of the experiment we can see that we reach an equilibrium in the emission of responses on the three devices (which were the initial goal). We can see that this participant who emitted at the beginning of the experiment most of his responses on the keyboard, used the three devices in an almost equal way.

Figure 36 depicts the proportion of responses on the force transducer during the different phases of the experiment for each participant. We can observe that the number of responses on the force transducer increased for all participants. Moreover, we can also observe that participants emitted more than 10% of their responses on this device during the second baseline.



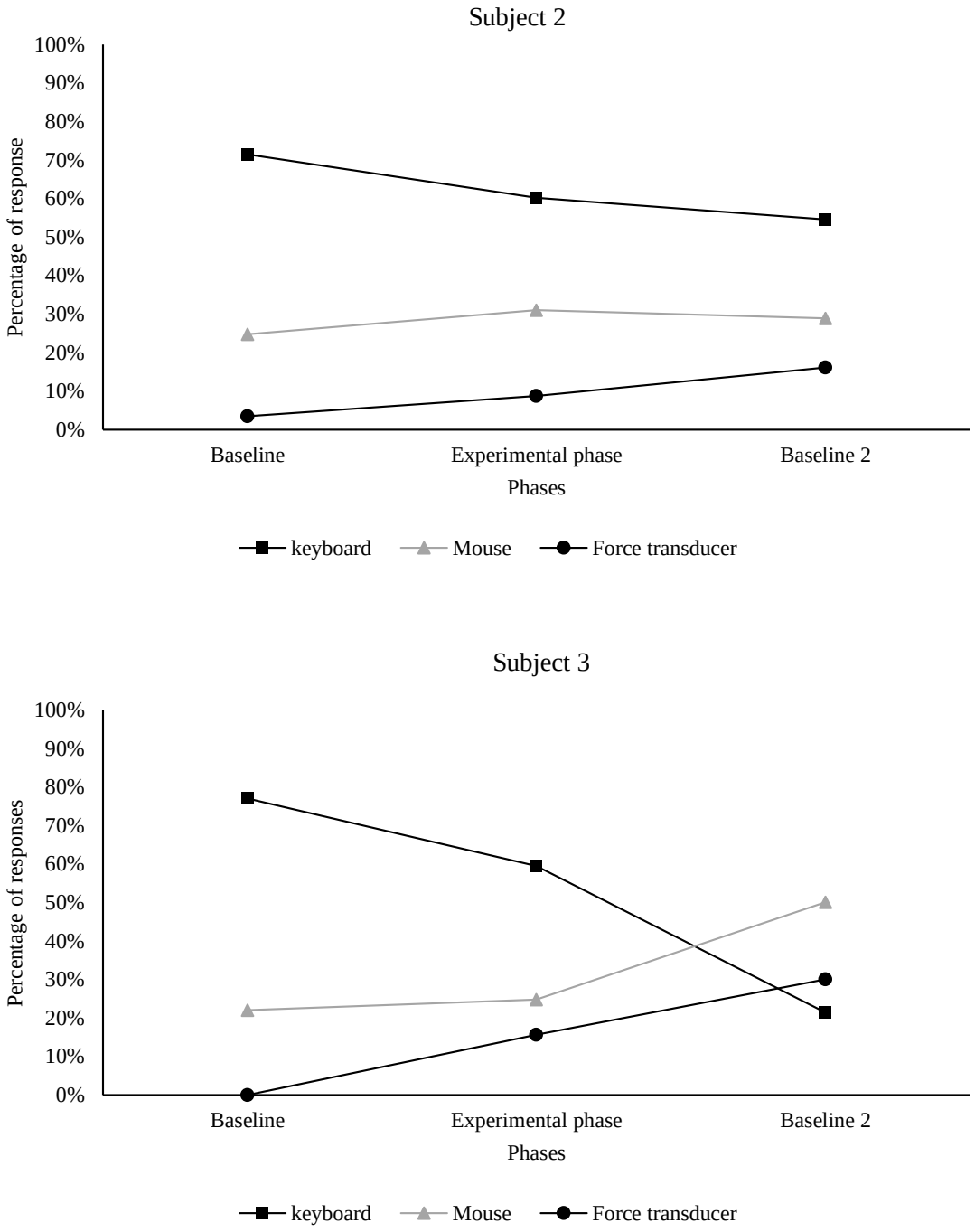



**Figure 35** : Percentage of response per device (Keyboard, mouse and Force transducer) during the baseline, experimental phase and the second baseline for the three subjects

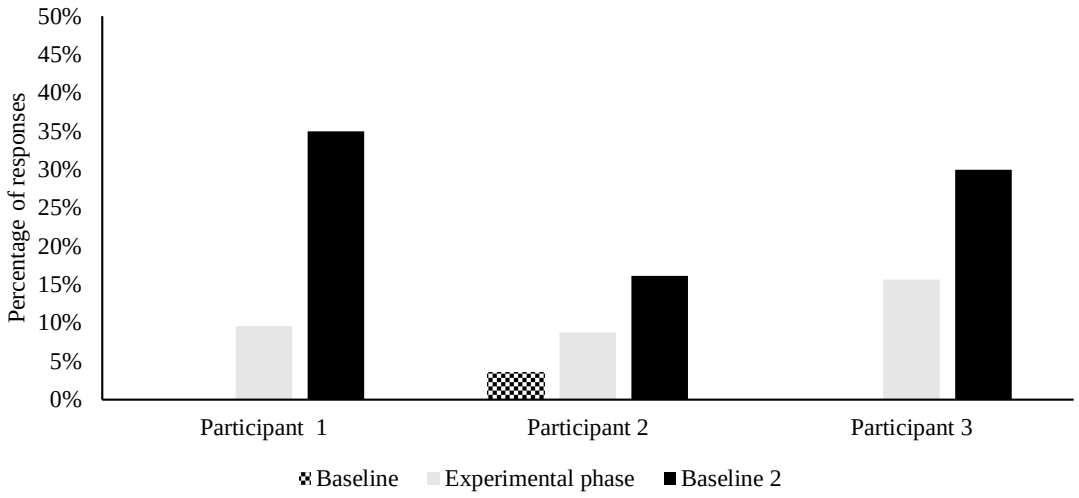



**Figure 36:** Percentage of responses on the force transducer during the different phases of the experiment (baseline, experimental phase, baseline 2) for each participant

## 3.2.6 Discussion

In this pilot study, we aimed at finding a different way to investigate behavioral variability with human. In order to do this, we set up an experiment on a computer game in which no instruction was given to the participants (except the prizes they can earn at the end of the experiment). In this game, participant behaviors were reinforced when responses were emitted on 3 different devices, a keyboard, a mouse and a force transducer. These different devices enable to emit different classes of responses. We assumed that the force transducer would be related with rare responses. In fact our main operational hypothesis was that reinforcing variability on the different devices enables to increase the probability to use the force transducer. We observed the relative frequency of response on each device. As predicted, we observed no response on the force transducer during the baseline. At the end of the first baseline most of responses was allocated on the keyboard and the mouse. Once, we introduced the experimental phase, responses which were emitted at high rate on the mouse and the keyboard were no longer reinforced (because of the number of responses emitted on these two devices, first responses emitted by the participant did not reach the criterion to get reinforced). During this phase, many variable responses were observed but not recorded because of the absence of relation with reinforcement criterion (i.e. when they are asked to recapitulate the experiment some participants reported that they touched the screen, stand up, tried to use the force transducer as a mic). At the end of the experimental phase, we observed that without

shaping, responses were emitted on the force transducer. This observation confirmed that reinforcing variation may facilitate the acquisition of rare responses.

In the experiment, the use of different stimulus as consequences aimed at creating more motivation. We assumed that different consequences had different reinforcement values: pictures, soda and cinema ticket. The higher reinforce value was associated to the cinema ticket which were associated with the low frequency of response. The soda was associated with a medium frequency of response. Last, pictures was associated with more frequent responses.

The relation between the different reinforcers and the relative frequency could be an interesting point to analyze. As emphasized in many experiment, the motivation to respond is different considering humans and animals (2009). In fact, the context is quite different, in experimental settings with animals, deprivation increases the probability for food to be a reinforcer (Michael, 1993). In human studies, token as reinforcers is widespread (Hackenberg, 2009), but it seems to produce more disparity in results (Maes & Van Der Goot, 2006). However, further analysis on the relation between consequences and variations should be an interesting point. In fact, these relations can bring more information on learning processes in which variability enable to have access to more consequences in the environment. A parallel could be done with development of skills in human lifespan. If we observe a toddler who is learning to walk, he has to try over and over to acquire the possibility to walk. In the same time if the emission of the same behavior is not susceptible to be disrupted by environmental changes, it may miss the opportunity to be in contact with new consequences. At some level, variability provides a basis upon which responses which are rare is possible, but once again, it has to be sensitive to consequences to enable selection.

This pilot study can be a basis to use a different methodology to investigate operant variability. However, the lack of participants, and the duration of the experiment may be severe limitation bias which prevent any conclusion. Moreover, further investigations should include more specific contingencies in the relation between variability and consequences. We can imagine an experiment in which, we could experimentally investigate motivating operations and behavioral variations across different classes of responses. A motivating operation is a process consisting in altering the reinforcement value of a stimulus, using deprivation for instance to increase its value or satiation to decrease it. Using different reinforcement, and

investigating their interaction with variability may bring more information in learning processes.

# 4. Chapter 4: General Discussion

## 4.1 Overall Aim of Thesis

This thesis investigates behavioral variations as an important variable to study behavioral changes in Humans (Hallgrímsson, & Hall, 2011). For decades, the place of variability has been subject to many debates. From the essentialist approach, it is an intrinsic variable which cannot be controlled and which is merely the imperfect reflect of a true underlying variable. On the contrary, the behavioral approach, based on a selectionist perspective, assumes that behavioral variability can be altered by environmental contingencies. From this perspective, behavioral changes result from the interaction between behaviors and environmental contingencies. In this interaction, behavioral variations are the basis upon which selection is possible (Palmer & Donahoe, 1992; Machado, 1993; Da Silva Souza, Abreu-Rodrigues & Bauman 2010). The epistemological divergences between these two perspectives have led to differences in the way researchers investigate natural phenomena. In fact, to our opinion, every concept's definitions depends on the perspective taken. Essentialism influences have led to the use of hypothetico-deductive methods to investigate steady state processes. Selectionists influences have led to investigate behavior and its environment. In this context, behavior analysis is maximally descriptive and limits inferences (Palmer, 1991; Schlinger, 1992). Interestingly, both perspectives have let apart the impact of behavioral variation in behavioral changes. This is even more surprising, considering the place of variability in behavior analysis and the selectionist analogy (Packer, 1992). Based on the assumption that behavioral variation can be altered by environmental contingencies, there has been a growth of interest in the topic since the 60's, and this, mostly with animal (Neuringer, 1991; Runco, 1994; Neuringer, 2002; etc..). These experiments have demonstrated that behavioral variation can be considered as an operant dimension of behavior. First, they found that behavioral variations can be controlled by antecedents and consequences. Second, investigations on animals demonstrate the relation between behavioral variations and the acquisition of rare responses. This latter result failed to be replicated in investigations on humans.

Considering the lack of investigations on behavioral variability in Human we have carried out two set of studies which were inspired from animal literature. First, in experiment 1

and 2 we studied the effect of environmental changes on behavioral variations and repetitions. One way to investigate the impact of environmental change on a dimension of response is through a resistance-to-change test. We designed two experiments in which, in a first phase, we trained either variable or repetitive behaviors. When these two behaviors were considered to be learnt, we introduced a second phase of environmental change, which consisted of either extinction or non-contingent reinforcement for one of the two patterns. In order to compare the effect of these disruptions we split participants into two groups: on the one hand disrupters were introduced only for variable trained behaviors, on the other hand disrupters were introduced only for repetitive trained behaviors. In the first result, we succeeded in modulating the level of variability during training phases. Second, during the extinction test, we observed a slight increase in the level of variability for variable responses but not for the repeat group. In fact, we observed that when participants were trained to emit repeat or variable responses, they tend to continue the same pattern even during extinction phase. These results are similar to those find by Arantes, Berg, Dien and Grace (2012). We observed in both experiments the effect of contingencies on the level of variability of behaviors. The interactions between a given pattern of response and environment are interdependent. On the contrary, using a VT schedule of reinforcement tended to decrease the response rate and prevented us from observing significant results.

If behaviors are known to endlessly change, the environment changes too. At a certain level, these changes affect behaviors – which affect the environment in return. When we observe behavioral changes: among these behaviors, some are adaptive, others can be maladaptive. However, selection, as a non-goal-oriented process does not create the distinction between these two types of behaviors. Considering that behaviors can be maintained despite environmental changes and that others are susceptible to change. Investigating to what extent behaviors and the environment change is a first step to understand behavioral changes. Behavioral variations are at some level an attractive feature to understand behavioral changes but alone, it is only one feature among others.

However, one major point results is in the opportunity to select new responses when the environment changes. We observed that there was a little change in the number of possible sequences on extinction for variable behaviors. In other words, extinction did not increase significantly the number of possibilities for variable behavior. This result is not surprising even

though interesting because in our experiment we had 27 possibilities. We observed that during the training phase in both experiments participants emit more than 90% of the possibilities in the variable condition and less than 5% in the repetitive condition. The interesting point is when we look at the data with repetitive trained behaviors. Indeed, we observed that even in extinction, the number of possible did not increase even though extinction is supposed to increase variability. These results mean that on certain contingencies, the continuum between repetition and variability is less affected by environmental changes. These results are congruents with literature which demonstrated that history of reinforcement has a great impact on the emission of operant variations and repetitions (Souza, Abreu-Rodrigues and Boumann, 2010).

The first question that we can address is to what extent these degrees of variations could affect behavioral changes, learning or development? At a certain level repetition is necessary for the acquisition of new response. If we observe a toddler who is learning to walk, he has to try over and over to acquire the possibility to walk. In the same time if the emission of the same behavior is not susceptible to be disrupted by environmental changes, it may miss the opportunity to be in contact with new consequences. At some level, variability provides a basis upon which responses which are rare is possible, but once again, it has to be sensitive to consequences to enable selection. On the one hand a condition enables to encompass 90% of the possibilities, on the other hand the other condition enables to encompass less than 5% of the possibilities, and both did not increase even in extinction. The emergence of a new behavior in development can be viewed as the selection of one response among the 10% remaining for the variable group, and 95% remaining for the repetitive group. These experiments were a basis upon which we asked ourselves several questions. If behavioral variations enables to observe a larger panel of possibilities than repetition does, it should facilitate the acquisition of rare responses. This could be true if we observed an increase of the number of possible during extinction and then the selection of a given response.

In the second set of experiments, we aimed at investigating the effect behavioral variability in the acquisition of rare responses. The study 3 is divided into two parts, a main study and a second pilot study. The initial experiment (experiment 3.1) aimed at investigating to what extent training behavioral variations could facilitate the acquisition of rare responses. Instead of using the traditional way to investigate behavioral variations and selection (Miller &

Neuringer, 2000; Maes & Van Der Goot, 2006; Doolan & Bizo, 2013), which consists in reinforcing concurrently variation and a target rare response, we proposed to train behavioral variations first, and then to learn target rare responses. In this experiment we compared both variable and repetitive behaviors. We obtained several results: first, we observed that the group in which variable behaviors were trained was more efficient in the acquisition of rare responses compared to the repetition group. Secondly, we observed that, even if the repetitive group learnt the rare responses slower, we can observe an improvement of the performance from one session to another. Based on this experiment and inspired by Holth study's (2012) we designed a pilot study in which we investigated behavioral variations across different classes of responses. More precisely, we investigated how variations can be transferred to different topographies of responses. In this experiment we used different devices, including a mouse, a keyboard and a force transducer. Based on parallel experiments, we assumed that force transducer is an unknown device which evoke no response. To increase the motivation of participants, we associated different level of quality of reinforcers to different level of variations. This experiment was made of a baseline, an experimental design and a second baseline. Globally, we observed an increase for the three subjects from the baseline to the second baseline in the use of the force transducer. In fact, participants which emitted no response on the force transducer but on the mouse and keyboard tend to emit many topographies of behaviors. During the debriefing, participants were asked to list different responses which were emitted during the experiment. The 3 participants admitted for instance that they tried to tap on the screen before using the force transducer. Next experiment should contain a camera to assess how responses variations occur and how they are selected. In the same way, this experiment failed in assessing the importance of the different reinforcers. A quantitative analysis in the interaction between the reinforcers and the degrees of variations should be included in further research.

These studies have demonstrated that behavioral variations can be a subject of matter in Human. We observed similar result than those observed with animals (Neuringer, 2002). Investigating behavioral variation as a dependent variable to understand behavioral change is the first step. In fact, considering that behavioral variation can be modified by environmental contingencies, and that it facilitates the acquisition of rare responses, one can ask how far these results can be generalized and applied in natural settings.

## 4.2 Behavioral changes and Development

Understanding conditions under which behavior changes, has been the main topic addressed in behavior analysis from decades:

*""Since Darwin, the central project of evolutionary biology has been to explain the origin of biodiversity – to determine how novel species and their characteristics have evolved" (Thorton, 2006, p.157). Operant conditioning can be described in similar terms: Since Skinner, the central project has been to explain how operant behaviors originate and change. To explain biodiversity, on the one hand, and behavioral diversity, on the other, we must consider the variations from which each emerges."* (Neuringer, 2009)

Based on this approach, authors (Bijou, 1961; Gewirtz & Pelaez-Nogueras, 1992; Gewirtz, 1991; Susa & Schlinger, 2012) have described a parallel between the way behavior analysis investigates behavioral change and the concept of development. According to Bijou & Baer (1965), development can be considered as progressive changes in the way the behaviors of an organism interact with its environment. Development research investigates these changes from birth till the end of life. Depending on the point of view, there are different ways to encompass development. First, changes over the lifespan can be considered to be orderly, systematic and universal across time. Through this prism, behavioral variations are a confounding variable, no more, no less. This perspective is directly influenced by the essentialist approach described in our introduction. In this approach, changes are described as stable and directly dependent on time. This way to investigate behavior can considered as direct successors of the biographical sketches and essentialist studies from the 19$^{th}$ century. Traditional textbooks describe developmental psychology as the science which studies the evolution of behaviors and psychological functions during the human lifespan (Godefroid, 2001 p87). Commonly, psychological functions refer to all internal processes responsible for behaviors. In order to investigate this evolution, research is focused on the observation of topographical change of behaviors (Taine, 1876; Darwin, 1877; Piaget, 1967). This method of investigation consists in describing the topography of behavioral changes either at different moments (i.e. longitudinal studies) or with different subjects of a given population (i.e. transversal studies). The description of changes can be observed as an orderly, systematic and predictable process (Bijou & Baer, 1961). First, developmental changes are considered to be

orderly because of their sequential aspect. The description of sequences of changes has led to the elaboration of stages theories which provide description in chronological periods of apparent behavioral stability (Thelen, 1992; Piaget, 1947). Secondly, changes are considered to be systematic and universal because all human beings are supposed to go through the same stages. When investigating development in this way, age is considered to be the independent variable. Indeed, age defines the different boundaries attributed to the emergence of specific skills. However, according to traditional developmental psychology, the process which determines necessary steps for the emergence of new skills is named maturation. This process is directly related to the age: as time passes by, the organism's repertoire is made more complex. In parallel, Maturation is considered to be the process responsible of organism changes. It refers to changes directly related to time (e.g. age) that occurs during the lifespan of an organism. Maturation as a driven process has led to model development linearly (Novak & Pelaez, 2004). Linear models conceptualize development as a unidirectional straight path in which changes are considered to be proportional. This simplistic conception of development has been replaced by transactional models in which changes are considered to be the result of the bidirectional relation between the maturation of an organism (i.e a child) and its environment (Sameroff, 2009). Indeed, this framework assumes that the maturation of an organism is not the only variable responsible for development, and that environment plays a role too. Figure 37 illustrates one example of this cartography. In this instance, we can observe the evolution of language topography from 0 to 7 years of age. This chart describes precisely how language is being made more complex during the child's lifetime. We can observe that, as presented in the introduction, the age and the topography of behavior are the main variables investigated. Traditional developmental psychology is able to describe what skill might appear at what age, but fails to explain the process of development. At this point, because they have mainly been focused on steady state processes, traditional psychology has rarely investigated the different level of variations which occur when behavior changes.

Indeed, if development can be assessed at a macroscopic level as a steady state process, the opposite is shown at a microscopic level. Actually if we observe development from a moment to moment scale, it looks more chaotic (Thelen & Smith, 1994). An example of these instable patterns can be found in motor acquisition. When learning to walk, infants globally display the same behavior. They start with the lying down position and go through the sitting position, crawling, standing up and then walking. This description consists in focusing on the topography

changes and it appears to be regular. However, when we look closer, all infants do not crawl in the same way, and there is large variability in the "crawling" pattern from day to day. In this context, we can observe that behavioral variations are not investigated because of the theoretical framework. However, there has been too few attempts from behavior analysts to investigate development (Schlinger, 1992; Neymy, Pelaez, Carrow and Monlux, 1997).

**Figure 37:** Adapted from Krashen & Terrel (1983). Instance of study in stage theories: acquisition of language (Krashen & Terrel, 1992)

| Stage | Characteristics | Approximate time frame |
|---|---|---|
| Preproduction | The student<br>• Has minimal comprehension<br>• Does not verbalize<br>• Nods « Yes » and « no » | 0-6 months |
| Early production | The student<br>• Has limited comprehension<br>• Produces one- or two-word responses<br>• Participates using keys words and familiar phrases<br>• Uses present-tense verbs | 6 months- 1 year |
| Speech emergence | The student<br>• Has good comprehension<br>• Can produce simple sentences<br>• Makes grammar and pronunciation errors<br>• Frequently minsuderstands jokes | 1-3 years |
| Intermediate Fluency | The student<br>• Has excellent comprehension<br>• Makes few grammatical errors | 3-5 years |
| Advanced Fluency | The student has a near-native level of speech | 5-7 years |

## 4.3 Behavioral variability: seeking for different perspectives

Transition between the absence of a behavior and its apparition could be the core of behavioral changes investigations. Developmental psychologists have developed different ways

to describe these transitions but behavioral variability is not part of these descriptions. However, despite its interest on the topic, behavior analysis did not provide quantitative tools to investigate behavioral variability. One possible way to investigate the dynamic of behavioral changes comes from dynamic system theories (Thelen & Ulrich, 1991; Thelen & Smith, 1994; Novak & Pelaez, 2004). According to Thelen & Smith (1994) to understand development, one must identify relevant variables and to determine how each variable interacts with each other.

## Dynamical system theory and Variability

The dynamic system theory could be considered as a complement to behavior analysis and traditional developmental psychology to explain development. Actually, in the dynamic system theory, behavioral variations are the core to understand development. Instead of considering that development is linear, researchers consider that it is multi-determined. It is considered to be the result of five factors: history of interaction, genetical constitutional make-up, current physiological conditions, current environmental conditions and behavioral dynamics. In fact, development can be viewed as a system in which all these parameters are in action. All parameters interact with each other simultaneously. This is why at a microscopic level development seems to be erratic and unpredictable. Instead of taking a picture at a moment T and then at a moment T+1, dynamic system approach grasps behavioral change as a continuous system in which different factors are in action. In this context, the influence of the five factors are not proportional. A change in initial condition (which can be defined by all the elements appear to be the starting point to a final state) leads to a great change of the system. All these parameters are in action in a non-proportional way. In these interactions, one change leads to the change of all parameters (Thelen & Smith, 1994). This description of development can be useful to investigate variability and transitions between two different states. For instance, in experiment 3.2, participants did not press the force transducer instantaneously. In fact, many behaviors which were not recorded were emitted before it. Applied to the emergence of walking, at some point, from the behaviors of “crawling” to “the standing up movement”, behaviors seem to be chaotic. In fact, coming together and reorganized all those parameters in action become a more stable pattern similar to the known behavior “standing up” (Novak & Pelaez, 2004).

Dynamical system approach could be a complement to behavior analysis in a way that the structure of a behavior is controlled by consequences. As previously described, one class of responses may enable to the organism to have access to specific stimulus in the environment when other classes do not. In our example, crawling enables to have access to stimulus which are on the floor, standing up may help to have access to stimulus which are not accessible on the floor. Dynamical system theories would provide a way to explain how a child switches from one position to others thanks to behavioral variability. In this context, we propose, in futures experimentations to investigate development and behavioral variability thanks to dynamical system theories. In fact future experimentation should provide more information on the different operations responsible of behavioral changes. Once we consider that behavioral variability is only one parameter which is responsible for change, further investigations on the topic must be carried out.

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