Non-random Human Performance under Conditions of Lacking Information

Sergey S. Tarasenko (sergey@cog.ist.i.kyoto-u.ac.jp)
Toshio Inui (inui@i.kyoto-u.ac.jp)
Department of Intelligence Science and Technology, Graduate School of Informatics,
Kyoto University, Yoshida-Honmachi, Sakyo-ku, Kyoto 606-8501, Japan

Niyaz M. Abdikeev (nabd@rea.ru)
Faculty of Informatics, Plekhanov Russian Academy of Economics,
Stremyanny pereulok, 36, Moscow 115998, Russia

Abstract

Many researchers have investigated implicit and explicit aspects in human behaviors. The Sequence Learning (SL) paradigm is one of the approaches used to investigate these aspects. The learning performance in SL tasks has been broadly studied. However, the guessing phenomenon has not yet been investigated, although it plays important part in a variety of human behaviors. The SL paradigm was adapted for the purpose of the guessing phenomenon research and used as basis for experimental design. The results show that human performance is non-random under conditions of lacking information, and both implicit and explicit aspects are found under these conditions. It further appears that under these conditions implicit knowledge is related not only to sequence learning itself, but also is assumed to indicate pre-knowledge of some kind playing crucial role.

Keywords: sequence prediction; non-random performance; guessing; sample dynamics.

Introduction

Over the last few decades, the attention of cognitive scientists has been attracted to investigation of the concept of implicit learning in human behavior. Numerous definitions of implicit learning have been offered and are listed in a review article by Frensch (1998). As suitable in the context of the present study we wish to employ here the following definition: implicit learning implies that information is acquired without intension and the resulting knowledge is difficult to express (Dienes & Berry, 1993).

The concept of implicit learning has been investigated together with another supplementary concept, that of explicit learning. In contrast to implicit learning explicit learning implies intentional learning and the resulting knowledge is easy to express.

Since the terms 'implicit' and 'explicit' refer both to the learning process and its resultant knowledge, we will use the term 'aspect' together with these terms to reflect mentioned duality when speaking in general.

In this context we will refer to the Sequence Learning (SL) paradigm as one of the approaches proposed to research implicit and explicit aspects. This paradigm was first described by Nissen and Bullemer (1987). The main idea of the SL paradigm is the learning of sequence rules during a stimulus sequence presentation.

Some researchers have conducted psychological experiments in frames of the SL paradigm. Lewicki, Hill and Bizot (1988) investigated non-conscious information processing. Cohen, Ivry and Keele (1990) investigated attention and structure in SL and control of automatic processes.

Others have addressed their investigations to the understanding of mapping between cognitive abilities involved in SL and neural mechanisms (Cleeremans & McClelland, 1991; Sun & Peterson, 1998).

An important question relates to whether the implicit and explicit aspects can be separated one from another. This question has been answered in the positive, for example, by Lewicki, Czyzewska and Hoffman (1987) and Willingham (1998), but nevertheless, situations in which only one aspect occurs are very rare and demand special conditions (Sun, Merril & Peterson, 2001).

Most recently, interaction between implicit and explicit aspects and a connectionist neural network which is able to model both aspects independently as well as their mutual interaction were proposed by Sun, Slusarz and Terry (2005).

Prediction and Guessing

The purpose of all studies cited above was to investigate knowledge acquisition during the learning process. The learning process was organized as a stimulus sequence (event) presentation where elements of stimuli are presented before a participant or a neural network responds. Thus, information about the sequence was presented first and the responses were feedbacks based on sequential information. In addition, training often preceded an experimental task. Thus, participants acquired some knowledge before experimental tasks.

In contrast a reciprocal situation takes place when no training is provided and information on the stimulus sequences is presented only after the action of a participant. The SL performance was investigated under these conditions in the present study.

The principal difference of this approach from the usual SL paradigm is that the participants are first required to produce estimation of a stimulus sequence element, rather than they are first presented a stimulus sequence element. Thus, information on a stimulus sequence is presented for the first time only after a participant's estimation. This fact and absence of training guarantee that during the first trial participants have no information about a stimulus sequence.

In this context we introduce the terms 'prediction' and 'guessing', while the term 'estimation' is employed as general indication of participants' actions.

In mathematical sense, prediction is understood as the extrapolation of some event's dynamics based on the previously collected data about the event.

Prediction plays important part in a variety of human social behaviors. Besides, prediction also has a great part in routine human functioning, especially, motor control. The importance of prediction in routine human actions, such as grasping, was formulated by Inui (1998) with regard to motor sequence prediction learning hypothesis.

It is often necessary to estimate the future values of some event's dynamics in the lack of adequate information about the event. In this case, under our terminology, the term 'prediction' is replaced by the term 'guessing'.

Thus, in a situation when all the rules underlying a stimulus sequence have been presented to a participant at least once, we use the term 'prediction' to describe the conditions under which a participant is performing estimations, whereas the term 'guessing' is used when not all the underlying rules of the sequence have been made available to a participant. These terms refer to the level of information that has been presented to a participant, but not to that actually acquired by a participant.

Guessing implies acting on incomplete information, and it is important to understand how human beings produce behavior in such situations.

Pre-knowledge and Basic Processing Algorithms

The approach described above allows to investigate existence of some pre-knowledge which is possibly used to make estimations when no information about an event is given.

It is assumed that "the brain does not invent a special processing mechanism for each cognitive function, but adapts a similar mechanism for a particular type of processing" (Borisyuk, Denham, Hoppensteadt, Kazanovich, & Vinogradova, 2001). Thus, human information processing mechanism is expected to contain some set of Basic Processing Algorithms (BPAs).

Numerical Sequence Decomposition

Any numerical sequence (NS) can be presented as a sequence of runs (directions) and a corresponding sequence of absolute values of the first order adjacent differences. The sequence of runs characterizes relative allocation of any two adjacent elements of a given NS.

In general, the dynamics of any NS can be presented using two domains – quality and quantity. The quality domain is realized in the form of runs dynamics, while the quantity domain is represented by a sequence of corresponding adjacent differences values.

Runs dynamics illustrates two mutually exclusive types of NS behavior: direction change and stability. To allow definition of either, at least two consecutive adjacent differences are required. Stability is identified when any two consecutive adjacent differences equal zero, or when they are of the same sign. Direction change is identified when two consecutive adjacent differences are of different signs, or when only one of them equals zero.

A series consisting only of direction changes caused by signs mismatch of consecutive adjacent differences is called an Oscillatory dynamics or an Oscillation. A series containing no direction changes is called a Stable dynamics. Response series which can not be classified either as Oscillation or as Stable is called a Mixed dynamics.

Because the runs dynamics provides only two types of NS behavior, it is possible to devise a stimulus sequence consisting of consecutive binary choices with the same probability of selection. This sequence is a simplified model of a NS in which absolute value of an adjacent difference can be only either 0 or 1.

It is possible to reformulate the purpose of present study in terms of runs dynamics, that is, to examine runs dynamics of various shapes (sample dynamics) that occur in participants' responses under conditions of guessing.

The Present Study

The purpose of this study was to investigate the manner in which estimations of the next element in a stimulus sequence are produced under conditions of incomplete information and the role played by pre-knowledge. Estimations could be the realization of the above-mentioned BPAs at the behavioral level.

We have begun with a brief description of general framework of the study and basic definitions. This is followed by a description of the experiments and results. The evidence for sample dynamics during the guessing is laid out in the discussion of experimental results. Then we discuss sample dynamics and implicit and explicit aspects. The final section presents our conclusions.

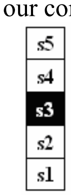

Figure 1: 5-by-1 BP used in Experiment 2.

Two experiments were conducted. In both, Block Patterns (BPs) (Phillips, 1974; Inui, 1988) were used to generate stimulus sequences. The dimensions of a BP are presented as (height-by-width). Each column of a BP consists of cells, representing choices. Each cell (choice) is called a state. The enumeration of states is performed upwards starting from state 1 (s1). A sample enumeration is shown in Figure 1. No enumeration was provided to the participants during experiments.

Basic Definitions

In accordance with above definitions of guessing and prediction, entire response series could be divided into two phases: a guessing phase and a prediction phase.

The determination of ordinal number of the trial (step) during a stimulus sequence presentation when the participant acquired complete information about a stimulus sequence in general is a difficult question and requires independent research. However, it is possible to determine the step when from the point of view of the sequence structure all the underlying rules have been presented for the first time. This step is used to define the end of the guessing phase of the participants' responses. Nevertheless, in case when it is easy to identify the particular step of the entire information acquisition by the participant, we took this step as the end limit of the guessing phase.

We employed BP-based sequences with a structure that included two underlying rules which are a BP structure and BP repetitions. The sequence was presented to the participants element-by-element. Thus the guessing phase of the experimental task takes place at least during the first (n+1) steps of the sequence presentation, where n is the width of the underlying BP. During the first n steps a BP structure is first presented entirely, then during the (n+1)th step the information regarding repetitions is first presented.

Since during the first step participants do not have any information about stimuli and selection of any state has the same probability, the first step is called 'the blind choice step'. Learning process of underlying sequence rules starts from the second step, when actual element of a stimulus sequence is first presented.

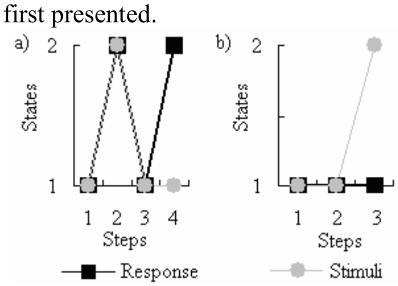

Figure 2: Examples of the inertia effect

We also introduce the term 'inertia effect'. The inertia effect describes situation when a series of correct participant's responses is followed by a wrong one. However, the entire response dynamics including incorrect response reflects an obvious general dynamics. Appearance of the last incorrect response characterizes the inertia effect. The examples of the inertia effect are presented in Figure 2.

Experiment 1

Objectives

The first goal of this experiment was to look for sample dynamics in the participants' guessing under conditions of stimulus sequences consisting of binary choices with equal probability of selection. The second goal was to examine existence of implicit and explicit aspects and relationship of these aspects with the response dynamics.

Method

Participants A sample consisted of 169 students of three universities. There were 94 males and 75 females and the average age was 21 year (SD = 2.87). All participants had normal or corrected to normal vision.

Materials Six 2-state BP-based sequences (conditions) were used as stimuli in the experiment. Each BP-based sequence was composed using 5 repetitions of an underlying 2-by-3 BP. BPs shown in Figure 3 were used as underlying BPs.

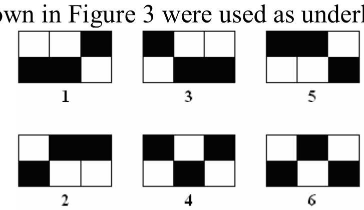

Figure 3: 2-by-3 BPs used in Experiment 1.

Participants were tested individually and were seated approximately 45 cm from the computer screen. To present stimulus sequences a 17-inch color computer monitor was used. Screen resolution was set to (1024 width x 768 height) pixels. Participants used a mouse to input responses.

The visual angle of separate cell is (1.23° wide × 1.23° high). The visual angle of a 2-state column is (1.23° wide × 2.55° high).

Procedure Participants were distributed among different conditions with statistically non-different frequencies. Each participant performed only one sequential task. Before starting an experimental task all participants read written instructions. No practice was provided for any of the participants. BP-based stimulus sequences were presented to participants on computer screen.

Stimulus sequences were presented using the Identity Width Temporal Window Condition. Under this condition only one element (column) of a BP-based sequence was presented at a time. Each column appeared in a stable position: the center of the state column matched with the center of the screen.

Before starting the experiment participants performed fixation of the mouse cursor at the center of the screen. For this purpose participants were instructed to click black circle in the center of the screen and not to move the mouse cursor before the experimental task began. The visual angle of the fixation circle is (0.89° wide x 0.89° high).

Participants were instructed to choose one of the empty cells of the column on each step during the stimulus sequence presentation. After selection of a particular cell the participants were shown the actual element of the stimulus sequence in the same column. Thus, feedback was provided to the participants.

The experimental task continued in the same manner until the end of the stimulus sequence. The end of the stimulus sequence is indicated by message "Sequence is finished". Sample trial during a stimulus sequence presentation is shown in Figure 4.

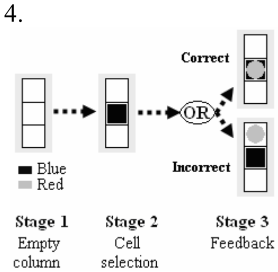

Figure 4: Sample trial of the experiment

Selection was indicated by a blue (black in Figure 4) square inside the chosen cell. Feedback was provided as a red (grey in Figure 4) circle inside the cell. In case of correct selection participants were shown a red circle on a blue square background inside the cell.

Inter-Stimulus Interval (I.S.I.) was not determined in advance, and varied with the participant's self-paced response time. In other words, the participant's choice time was not forced, and I.S.I. was taken as the sum of choice time and a one second delay.

Results

An analysis of the frequencies of different responses during the blind choice step showed a statistically significant difference between the frequencies of the response choices and chance, at the 0.5 level ($p = 0.014$).

Occurrence frequencies of various sample dynamics during the first two, three and four steps (consecutive sub-series) of the guessing phase are found to be non-random ($\chi^2(3,169) = 11.426$, $p = 0.010$; $\chi^2(7,169) = 16.325$, $p = 0.022$; $\chi^2(15,169) = 39.917$, $p = 0.001$, respectively).

Further, frequencies of dynamics during the first two steps were analyzed. The frequencies of opposite (1-2; 2-1) and same (1-1; 2-2) two consecutive states are 0.59 and 0.41, respectively. These frequencies were found significantly different ($p = 0.031$).

Next, the frequencies of dynamics containing the inertia effect were analyzed. The occurrence frequencies of dynamics containing the inertia effect of lengths 3 and 4 were found to be 0.08 and 0.12, respectively. The corresponding chance levels are 0.125 and 0.063, respectively. The Binomial test revealed significant difference between the frequencies and their corresponding chance levels ($p = 0.032$ and $p = 0.005$, respectively).

Discussion

This analysis indicates non-random nature for responses during the blind choice step. That is, even when no information about the stimulus sequence was provided, participants responded in a manner different from the chance. This appears to be evidence for implicit knowledge, but this knowledge is no way extracted from information about the specific sequence task.

The frequencies of various response dynamics during the first two steps were found non-random as well as during the blind choice step. Two opposite consecutive (1-2, 2-1) states dominated over two same consecutive states (1-1, 2-2). Thus, participants tend to choose adjacent elements of different states during the first two steps.

Furthermore, the frequencies of dynamics during all consecutive sub-series also found to be non-random.

The non-random appearance of consecutive sub-series (the longest sub-series is 4 steps) indicates existence of some knowledge throughout the entire guessing phase. In accordance to this and conditions of incomplete information provided to the participants, we imply that this knowledge is more likely to be implicit.

Non-random nature of the inertia effect also illustrates existence of some knowledge. However, the inertia effect is characterized by a series of correct responses which follow some obvious general dynamics together with last incorrect response. Existence of an obvious general dynamics may characterize that participants performed the last incorrect response according to the dynamics presented by previous correct responses. Thus, knowledge reflected by the inertia effect is more likely to be explicit.

Both types of knowledge during the first two steps and during the inertia effect are suspected to be of different characters – implicit and explicit, respectively. Thus, we imply that there should be the period of implicit and explicit aspects interaction during the guessing. The end of this period is characterized by conversion of implicit knowledge into explicit one. However, acquired explicit knowledge does not obligatorily contain the complete and correct information about the stimulus sequence.

Experiment 2

Objectives

This experiment aimed to verify existence of sample dynamics and implicit and explicit aspects under conditions of enhanced number of choices (5 states) when the correct response has the same allocation throughout the sequential task.

Method

Participants A total of 209 students of three universities took part in the experiment. There were 119 females and 90 males. And the average age was 21 years (SD=2.31). All participants had normal or corrected to normal vision.

Materials The same materials as in Experiment 1 were used except for the stimulus sequence. In this experiment only one BP of 5-by-1 dimensions was used. This BP was repeated 15 times. Thus, the stimulus sequence is present as continuous horizontal line in the middle of the state-column (state 3). The change of BP size caused a change in visual angle as well. Visual angle of a 5-state column is (1.23° wide × 5.34° high).

Procedure The procedure was the same as in Experiment 1.

Results

All the response dynamics produced during experimental task converged to the middle line. The convergence indicates that from a particular step (a step of convergence) onwards a participant produced only correct responses. With this sequence characteristic, it was possible to define the step when participants acquired the entire information about stimulus sequence and produced correct responses. The obtained data was analyzed from the point of view of response dynamics before convergence.

Responses during the blind choice step were analyzed as instances of three response variants: above the middle line, below the middle line, and in the middle line. The Chi-square categorical test revealed significant differences between the frequencies of occurrence of each response variant ($\chi^2(2,209) = 57.71$, $p = 0.000$).

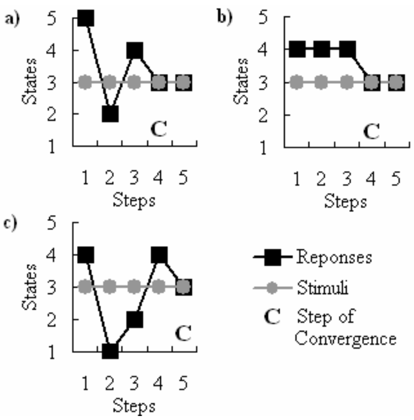

Figure 5: Examples of the dynamics of groups

Next, sub-sequences with the beginning at step 1 and the end at trail which is one step before the step of convergence were extracted from the entire response sequences. These sub-sequences were analyzed as instances of the three groups of dynamics: the Oscillation, the Stable and the Mixed. Sample dynamics for each group are presented in Figure 5 a), b) and c), respectively. The Chi-square categorical test revealed significant difference in the frequencies with which dynamics of different groups occurred ($\chi^2(2,209) = 43.53$, $p = 0.000$). The obtained frequencies for the Oscillation, the Stable and the Mixed groups are 0.27, 0.19 and 0.54, respectively.

The Average Length of Dynamics (number of steps) before Convergence (ALDC) for each group of dynamics and its corresponding standard deviation (SD) are presented in Table 1.

Table 1: ALDC and SD for groups of dynamics.

Groups	Convergence	
	ALDC	SD
Oscillation	2.67	0.65
Stable	2.00	0.60
Mixed	3.47	0.72

Differences between the ALDCs for the three groups were examined using the ANOVA. This test revealed significant difference between the means of the three groups of dynamics ($F(2,209) = 51,82$, $p = 0.000$). The homogeneity of variance test failed to reveal homogeneity of data variance ($p = 0.277$), but Tamhane's test confirmed significance of differences between the ALDCs for the different groups.

Discussion

An analysis of responses during the blind choice step showed non-random distribution of different responses' frequencies. This fact confirms the similar findings in the Experiment 1.

An analysis of frequencies of the three dynamics groups before convergence showed non-random distribution of frequencies of each group. The ANOVA test revealed statistical difference between the ALDCs for each group of dynamics. Thus, each type of dynamics implied a particular speed of convergence.

According to the data analysis the results of Experiment 2 confirm results of Experiment 1.

General discussion

The experiments described above illuminated the characteristics of the guessing phenomenon from different angles.

In Experiment 1 evidence for non-randomness of participants' responses during the blind choice step was found. In Experiment 2 the non-random nature was confirmed under conditions of more possible choices.

From the point of view of the implicit aspect, non-random distributions of frequencies during the blind choice step provides evidence for the existence of some implicit knowledge when no information is given about stimuli. Thus, this knowledge was not extracted from information on stimulus sequences.

The analysis of the entire guessing phase showed the non-random nature of the produced dynamics frequencies during each consecutive sub-series.

The dynamics containing the inertia effect of different length were found to take place with frequencies significantly different from the corresponding chance levels. The inertia effect is assumed to be a support for existence of explicit aspect and its interaction with implicit one during the guessing phase. However, more detailed research of this phenomenon should be held.

Experiment 2 is performed under conditions in which it is easy to distinguish step when the participant becomes able to use complete information about the stimulus sequence. The results of the second experiment provide not only qualitative description of dynamics during the guessing phase, but also define some quantitative characteristics of sample dynamics. Each group of dynamics is characterized by a corresponding convergence speed (ALDC) which significantly different from other groups. Thus, we can conclude that there are different mechanisms of human behavior responsible for production of each group of dynamics.

In early studies the implicit aspect "assumed existence of some potentially mysterious processes of passive, automatic and unconscious acquisition of abstract and tacit knowledge" (Cleeremans, Destrebecqz & Boyer, 1998). The appearance of sample dynamics and non-random nature of responses during the blind choice step provide support for existence of some pre-knowledge and thus retain this statement.

However, from the point of view of the guessing, implicit aspect seems to refer not only to the sequence processing, but also to the processing of stimulus sequence presentation area.

Besides, the results of the present study show that the oscillatory phenomenon is found under different conditions and its frequencies of occurrence are found to be different from chance level in all discussed cases.

Statistically significant differences of response dynamics' frequencies from the chance level points to the non-random nature of produced responses even under conditions of lacking information. Together with the mentioned above assumption of implicit aspect this fact retains idea about existence of a set of BPAs.

Non-random occurrence of oscillations under different conditions shows that oscillations can be part of BPAs that enables modeling of the guessing mechanism with oscillatory neural networks (ONN). Recently, oscillators have been applied to model different cognitive functions such as novelty detection (Borisyuk, 2001) and attention and memory (Kryukov, 2002). ONNs represent the non-connectionist approach. However, the possibility of its application for cognitive function modeling is supported by Sun at al. (2005).

Conclusion

In this study, we indicated the sample dynamics in the human guessing during the sequence learning tasks. The results of the conducted experiments retain existence of BPAs. Besides, implicit and explicit aspects were also found. According to the experimental data, the implicit aspect takes place when incomplete information about stimulus sequence is available, while explicit aspect is suspected to develop under the same conditions reinforced by a series of correct responses. Also the inertia effect is assumed to illustrate the interaction of implicit and explicit aspects during the guessing phase. However, more precise research of implicit and explicit aspects under presented conditions should be performed.

Acknowledgement

We would like to thank associated professor Koji Sakai, Kyoto Koka Women's University, for valuable comments and experimental assistance.

References

Berry, D.C., & Dienes, S. (1993). Implicit learning: Theoretical and Empirical aspects, Erlbaum.

Borisyuk, R., Denham, M., Hoppensteadt, F., Kazanovich, Y., Vinogradova, O. (2001). Oscillatory model of novelty detection. *Network: Computational Neural Systems, 12*, 1-20.

Cohen, A., Ivry, R.I., & Keele, S.W. (1990). Attention and structure in sequence learning. *Journal of Experimental Psychology: Learning, Memory and Cognition, 16,* 17-30.

Cleeremans, A., Destrebecqz, A., & Boyer, B. (1998). Implicit learning: news from the front. *Trends in Cognitive Science, 2, 10*, 406-416.

Frensh, P.A. (1998). One concept, multiple meaning: on how to define the concept of implicit learning. In M.A. Standler, & P.A. Frensch (Eds.) *Handbook of Implicit Learning* (pp. 47-104), Sage Pulications.

Inui, T. (1988). Properties of Human Visual Memory for Block Patterns. *Biological Cybernetics, 59,* 179-187.

Inui, T. (1998) Motor sequence prediction learning hypothesis, *Japanese Journal of Neuropsychological, 14,* 144-149.

Kryukov, V.I. (2002). Attention and Memory Model Based on the Principle of Dominanta and Comparator Function of Hippocampus, *Journal of Higher Nervous Activity*, *10*, 10-29.

Lewicki, P., Czyzewska, M., & Hoffman, H. (1987) Unconscious acquisition of complex procedural knowledge. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 13,* 523-530.

Lewicki, P., Hill, T, & Bizot, E. (1988) Acquisition of procedural knowledge about a pattern of stimuli that cannot be articulated. *Cognitive Psychology, 20,* 24-37.

Nissen, M.J., & Bullemer, P. (1987). Attentional requirement of learning: evidence form performance measure. *Cognitive Psychology, 19,* 1-32.

Shanks, D.R., & St Jonh, M.R. (1994). Characteristics of dissociable human learning system, *Behavioural Brain Science, 17,* 367 – 447.

Phillips, W. A. (1974). On the distinction between sensory storage and short-time visual memory. *Perception and Psychology, 16,* 283-290.

Sun, R., & Peterson, T. (1998). Autonomous learning of sequential tasks: Experiments and analyses. *IEEE Transactions on Neural Networks, 9,* 1217–1234.

Sun, R., Merril, E., & Peterson, T. (2001). From implicit skill to explicit knowledge: a bottom-up model of skill learning, *Cognitive Science, 25,* 203-244.

Sun, R., Slusarz, P., & Terry, C. (2005). The interaction of the Explicit and Implicit in Skill Learning: A Dual-Process approach, *Psychological Review, 112, 1,* 159-192.

Willingham, D. (1998). A neuropsychological theory of motor skill learning. *Psychological Review, 105,* 558-584.