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Neurobiological Dynamics of Goal-Directed Behaviour: Interplay Among Hippocampus, Basal Ganglia, and Mesolimbic Dopamine Pathway

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ABSTRACT

Goals, be it personal or professional, are fundamental to human development and of society as a whole. This paper explores the neurobiological mechanisms underlying the formation of goal-directed behaviour, focusing on the interaction between hippocampus, basal ganglia, and mesolimbic dopamine pathway which facilitates reinforcement learning. Phase 1 highlights the role of the hippocampus in providing a framework for habit formation, by combining declarative and episodic memories to the basal ganglia. Following this, Phase 2 showcases the basal ganglia facilitating the transition from conscious behaviour to automatic behaviours refining motor sequences through repetition and contextual cues provided by the hippocampus. Finally, at Phase 3, the influence of the mesolimbic dopamine system on synaptic plasticity, allows successfully linking goal-directed actions to positive reinforcement and habit formation. By dissecting these interconnected neural processes, the study aims to contribute to a deeper understanding of how motivation and cognitive adaptation are shaped by the brain's ability to translate goals into enduring habits.

INTRODUCTION

Human activity is driven by the pursuit of goals, irrespective of whether they are simply personal aspirations, professional aims, or educational milestones. It is essential to human motivation that they are capable of identifying what they want to achieve and subsequently meeting their targets, which all play a big role in shaping people's lives as well as the growth of society. This notwithstanding, effective goal pursuit, especially the transition from actions that are consciously controlled to those which are automatic is an important area of research in terms of science. In summary, the purpose of this work is to expand the present literature in order to reveal the dynamic neurobiological factors underlying the development of habit during goal-directed behaviour by exploring the interaction between the hippocampus, basal ganglia, and reinforcement learning. The findings will explain how the activity of these factors affects the efficiency of goal achievement and will contribute to a deeper understanding of motivation and cognitive adaptation by explaining the three phases which contribute towards the formation of goal-directed behaviour. Our hypothesis postulates that the hippocampus is necessary for event recording in relation to the goal, which is then in turn converted into a habit with the help of basal ganglia through neuronal plasticity and reinforcement learning related to the mesolimbic dopamine pathway. With particular attention, this study considers the brain factors that translate the goal-based attitude to habit formation and processing.

PHASE 1: THE HIPPOCAMPUS AND FRAMEWORK FOR HABIT FORMATION

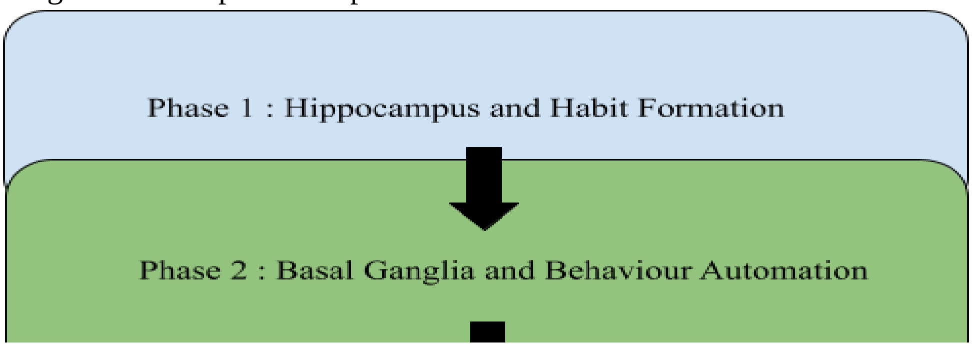
In order for one to set and meet goals, they need to engage in a range of intellectual activities including scheduling, decision-making and recalling information from memory. In these cognitive tasks, a number of brain regions collaborate, among them is the hippocampus, found in the medial temporal lobe. The hippocampus has been associated with the formation, organisation, and retrieval of episodic memories, which are memories of specific events or experiences in one's life, and also is responsible for the consolidation of short-term memory into long-term memory by transforming sensory input into a stable and coherent trace that can be later retrieved and restored (Eichenbaum, H. 2017). The hippocampus is crucial for declarative memory, which includes memories we can consciously recall, like facts and personal experiences, as it helps encode personal experiences, linking them together in a way that allows for flexible and inferential memory use, which allows for them to be recalled and used in different contexts, with research also showing that hippocampal networks record episodic memories as sequences of events and the locations where they happened, which in turn helps us remember not just what happened, but where and in what order (Eichenbaum, H. 2001). From the above, we deduce that the hippocampus plays a very essential role in the formation of declarative memory and also in remembering the combination of where and how. Another especially crucial function of the hippocampus is its ability to create a framework for habit formation by providing information about combinations of features to the striatum and that information was used to learn how to succeed at the task, with the hippocampus forming bound associations of multiple features that supported learning in the striatum about the configuration of multiple features in the environment (Arizona State University. 2019, March 6). Hence, this framework is provided to the basal ganglia by combining declarative memory with the episodic memory (Eichenbaum, H. 2003) in order to create a whole set of contextual cues which allow the completion of phase 1 i.e. formation of a framework for habit.

PHASE 2: THE BASAL GANGLIA AND BEHAVIOUR WITH A PURPOSE

Decades of research on the anatomy, neurochemistry, and neurophysiology of the basal ganglia have refined our understanding of the role of this brain region in motor behaviour, with extensive research into the region suggesting an increased role in human memory and learning, with a particular emphasis of the dorsal striatum region, which mediate a form of learning by forming associations between certain stimuli (things we experience) and our responses to them (Packard, M. G., & Knowlton, B. J. 2002). As the above-mentioned paragraphs suggest, the hippocampus plays the very important step of encoding and consolidating episodic memories relating to specific goal-related events, as well as contextual recollection (Eichenbaum, H. 2001), which makes it possible to carry out learned activities in the right place and is necessary for acclimatisation to habits. When people frequently engage in goal-oriented actions, a shift from conscious choice to automatic performance occurs. During the initial phase of learning a new task, neural activity in the basal ganglia is widespread throughout the entire action sequence, with studies involving chronic electrophysiological recordings in mammals show that during this phase, neural firing is not confined to specific parts of the task but occurs throughout the entire sequence and as the behaviour is practised and starts to become a habit, neural activity in the basal ganglia, particularly in the striatum, begins to concentrate at the beginning and end of the action sequence, known as marking the action boundaries where in the striatum, task-related neural firing becomes concentrated at the action boundaries, while non-task-related neural activity decreases and with continued practice and repetition, the neural patterns associated with the beginning and end of the action sequence become more pronounced and this repetition reinforces the habit, making it more automatic and ingrained (Graybiel, Ann. 2008). Hence, as mentioned in the first phase, the hippocampus and basal ganglia show a codependent relationship where the hippocampus helps create a framework for a habit/goal-directed behaviour by providing the striatum with contextual cues about the environments and other relevant factors, causing the formation of associations between these features, helping the basal ganglia to learn how to succeed in the task and with continued practice and repetition, the brain's activity patterns at the start and end of the task become stronger. This repetition helps reinforce the habit, making it more automatic and easier to perform without thinking. Hence, now the basal ganglia has assisted us in the completion of the second phase i.e. helping the habit become easier and autonomous, requiring less of a cognitive effort behind its completion.

PHASE 3: SYNAPTIC PLASTICITY AND MESOLIMBIC DOPAMINE SYSTEM

Within the interplay of basal ganglia and its influence on goal-directed behaviour, this system is enhanced by the mesolimbic dopamine system by enhancing synaptic plasticity, by connecting goal-directed behaviour to positive results, causing the action to become an automatic behaviour (Aboitiz, F., & Cosmelli, D. 2008). As per the previous literature and findings done on animals, the process is thought to occur as following :- the ventral tegmental area, consisting of dopaminergic neurons, is activated when an individual performs an action aimed at a particular goal causing the subsequent release of dopamine in the striatum and other regions within the basal ganglia (Wise, R. A. 2004). The action of D1 dopamine receptors, when they are activated in the direct pathway of MSNs, helps facilitate Long-Term Potentiation (LTP) , which in turn enhances synaptic plasticity in the basal ganglia (Surmeier, D. J., Plotkin, J., & Shen, W. 2009). Hence, through experience, the synaptic connections associated with successful goal-directed actions are strengthened via LTP. Research also suggests that when we indulge in reward-oriented behaviour, it gets associated with motivational salience, which in turn triggers dopamine activation, making us pay more attention to them and seek them out, helping us learn from those positive outcomes, which in turn helps refine future behaviour by updating the expected value of actions (Schultz, W. 2016). Dopamine is thus reinforcing those behaviour and actions that are associated with a positive or rewarding outcome, which is the formation of goal-directed behaviour. Additionally, the dorsomedial striatum is particularly important in this process, as it is associated with the cognitive aspects of goal-directed actions, allowing for the flexible adaptation of behaviour in response to changes in action-outcome contingencies or in the value of the outcome (Balleine, B. W., & O'Doherty, J. P. 2009). Therefore, the basal ganglia enable effective goal-directed behaviour with suitable cognitive supervision by mediating the selection and execution of activities most likely to result in desired outcomes through dopamine-mediated synaptic plasticity, allowing for the completion of phase three.



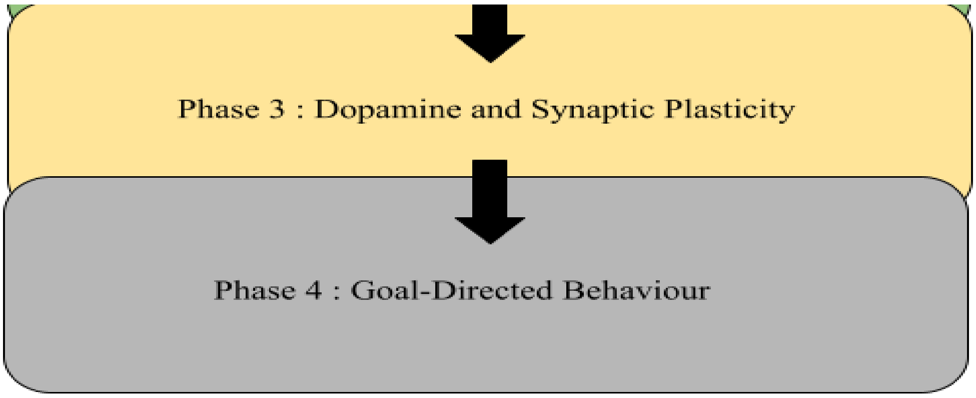


Figure 1 : Schematic Representation of the progression from conscious choice to automatic behaviour. 1)

Phase 1 : The hippocampus encodes and consolidates episodic memories to create a cognitive framework for habit formation followed 2) Phase 2 : The basal ganglia automate goal-directed actions by refining motor sequences, making them habitual and less cognitively demanding. 3) Phase 3 : The mesolimbic dopamine system enhances synaptic plasticity, linking successful goal-directed actions to positive reinforcement and solidifying habits. 4) Phase 4 : The interaction of these neural processes results in the establishment of efficient, automatic goal-directed behaviour.

CONCLUSION

To summarise, the elaborate interaction connecting hippocampus, basal ganglia and reward can explain the transition from controlling the action towards forming a habit. By preserving episodic detail together with contextual cues, the hippocampus enables habits to take root; meanwhile, basal ganglia such as striatum tweak neural circuits to make it smooth for habits to be performed automatically in due course. This progression from conscious choice to automatic behaviour is enhanced by synaptic plasticity and supported by the mesolimbic dopamine system, which connects goal-oriented behaviour to positive results. Knowledge of these brain-associated forces serves to extend our comprehension of human motivation and cognitive alteration and to provide methods for making goal attainment and habit development better.

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LIMITATIONS

1. **Methodological Constraints**: Much of the research on basal ganglia and hippocampal connections uses complicated neural recordings or imaging methods, which may have spatial and temporal resolution limits and can have an influence on the accuracy with which brain circuits are mapped and the exact functions they play in habit development.
2. **Focus on Specific Brain Regions**: The study focuses on the hippocampus and basal ganglia, but it may ignore other brain areas involved in goal-directed activity, such as the prefrontal cortex, which is important for executive processes and decision-making.
3. **Variability in Reward Systems**: Individual variability in dopamine receptor distribution and

sensitivity may limit the generalizability of results on reward processing and habit development.

4. **Lack of Longitudinal Data**: The research primarily considers cross-sectional data or short-term studies, and longitudinal studies are needed to better understand how habit formation and goal-directed behaviour evolve over time.

IMPLICATIONS

1. **Integration of Additional Brain Regions**: Investigating the roles of other brain regions, such as the prefrontal cortex, in conjunction with the hippocampus and basal ganglia will provide a more comprehensive understanding of goal-directed behaviour and habit formation.
2. **Longitudinal and Developmental Studies**: Conducting longitudinal studies to examine how the processes of habit formation and goal-directed behaviour change over time and in response to different life stages, environmental factors, or neurological conditions.
3. **Personalised Approaches**: Research should explore individual differences in neurobiological responses to rewards and habits. Understanding how variations in dopamine receptors and other neurochemical factors influence habit formation could lead to more personalised strategies for behaviour modification.

DAS :

Data sharing not applicable to this article as no datasets were generated or analysed during the current study

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