



## Links between autonomic activity and implicit learning



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### ABSTRACT

The somatic marker hypothesis posits that autonomic activity occurring in response to specific stimuli aids in implicit learning, the learning of information without explicit awareness of what has been learned. This study investigated whether respiratory sinus arrhythmia (RSA), a measure of autonomic nervous system activity, predicted changes in implicit learning. The interaction of resting RSA and RSA reactivity (change in RSA during the implicit learning task) was associated with changes in implicit learning, with those who had higher resting RSA and greater RSA withdrawal during the task performing better. These findings contribute to a better understanding of the autonomic processes that may underlie implicit learning and are discussed in relation to potential links between autonomic activity, implicit learning, and decision making.

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### 1. Introduction

We learn even when we are not aware of learning taking place. Implicit learning is the process of gaining sensitivity to novel relationships or regularities among events in the environment, which are often probabilistic in nature, without conscious knowledge of what has been learned or that learning has even occurred (Reber, 1989). Implicit learning permits individuals to adapt their behavior to environments without expending conscious effort (Frensch and Rüniger, 2003) and may be experienced as intuitions or “gut feelings” about the available choices (Lo and Repin, 2002). In other words, even though we may not be consciously aware of learning, our bodies may be subtly influencing our responses to patterns in environmental stimuli.

According to the somatic marker hypothesis (SMH; Bechara and Damasio, 2005; Damasio, 1996), autonomic activity plays a key role in implicit learning processes. The SMH suggests that physiological “markers” occur within individuals in response to encounters with stimuli and that with repeated exposure, these markers then become associated with those events. Somatic markers will be reactivated in response to those stimuli in future experiences, even without conscious awareness of the stimuli’s significance, and will bias cognitive processing and behavior involving them (for a review, see Dunn et al., 2006). Existing research supports the claim that somatic signals, at least initially, assist with learning in uncertain environments, but the majority of this research has focused only on activity in the sympathetic branch of

the autonomic nervous system, and has largely ignored the parasympathetic branch.

The relationship between the brain and the autonomic nervous system is crucial to understanding the connection between the latter and individuals’ behavior. Both cortical and subcortical areas of the brain contribute to processes such as attentional regulation, affective information processing, and behavioral flexibility (Thayer and Lane, 2000). The coordinated activation of all of these processes is what allows individuals to adapt their behavior in the face of environmental challenges or changes (Thayer et al., 2012). For example, implicit learning involves a functional network of cortical-subcortical connections, with the prefrontal cortex acting as a hub that links brain regions related to memory and learning, such as the caudate nucleus (Yang and Li, 2012). In order to adapt behavior properly, there needs to be an appropriate balance between the sympathetic and parasympathetic nervous system (SNS and PNS, respectively); the former stimulates the body during stressful situations when a fight-or-flight response is needed and the latter promotes readiness to engage with (e.g., learn from) the environment. Research has suggested that this ability to regulate autonomic activity may be related to psychological self-regulation, which also relies on the prefrontal cortex to exert top-down control on other brain regions (Porges, 1992). Given this, PNS activity may be particularly important to consider when examining individual differences in higher-order cognitive functioning.

The current study focused on PNS activity and its role as a potential somatic marker in implicit learning. Although this is the first study on this topic, there is evidence that the PNS plays an important role in social and more explicit learning processes (Porges, 2007). To measure PNS activity, the impact of the vagus nerve, one of the primary conduits for parasympathetic influence on multiple organ systems, can be non-invasively assessed. Output from the brain, the nature of which is

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dependent on an individual's internal and external circumstances, travels to the heart via the vagus nerve. The vagus nerve acts like a “brake” on the heart (Porges, 2007), increasing cardiac output to facilitate blood flow for active problem solving or promoting fight-or-flight response (i.e., SNS activation) when the brake is withdrawn. The ability to flexibly engage and withdraw parasympathetic influence depending on internal and external demands is indicative of adaptive attentional and regulatory processes (Porges, 2003). This interplay of sympathetic and parasympathetic influence on the heart leads to variability in heart rate (i.e., heart rate variability or HRV). Because vagal activity fluctuates in phase with respiration (Frazier et al., 2004), researchers can document the variability in inter-beat intervals (i.e., the time between heartbeats) that occurs during typical breathing cycles, also known as high-frequency HRV (Berntson et al., 1997). This high-frequency HRV is also known as respiratory sinus arrhythmia (RSA). Therefore, RSA acts as an indirect measure of vagal-parasympathetic influence on the heart.

There is extensive research linking both RSA at rest as well as changes in RSA in response to a stressor (i.e., RSA reactivity) to a host of cognitive outcomes including explicit learning (Fairclough et al., 2005; Haley et al., 2008), executive functioning (Dushek et al., 2009; Hansen et al., 2003), fluid intelligence (Hinnant et al., 2013; Staton et al., 2009), and cognitive control (Marcovitch et al., 2010; Overbeek et al., 2014). Generally, this body of research suggests that a higher level of parasympathetic activity at rest (i.e., higher resting RSA) in conjunction with a decrease in parasympathetic activity in response to a challenge (i.e., RSA withdrawal) is associated with better cognitive performance. For instance, Hinnant et al. (2013) demonstrated that children with lower resting RSA and less RSA withdrawal during tasks measuring fluid cognition showed a significantly shallower slope of fluid cognitive performance across middle childhood. Fairclough et al. (2005) found that greater RSA withdrawal was associated with better performance on a demanding learning task and also predicted changes in performance across the task in sample of young adults.

Notably, all of these cognitive tasks with which RSA have been associated are explicit in nature. Given that executive functions (i.e., attention, working memory) are an integral part of implicit learning and that prefrontal brain regions are active during this type of learning (Pascual-Leone et al., 1996; Simon et al., 2012; Yang and Li, 2012), it stands to reason that RSA may be related to implicit learning in a similar fashion. No research to date has examined the relationship between autonomic activity and performance on a task that specifically measures implicit learning. This study aims to fill that void by providing a more nuanced understanding of the physiological processes underlying implicit learning, and the possible implications for decision making under uncertainty. We investigated whether RSA measured at rest and during an implicit learning paradigm, the Triplets Learning Task (TLT; Howard et al., 2008), were associated with performance on that task. Additionally, we examined the potential interaction between resting RSA and change in RSA during the task (RSA withdrawal) as a predictor of implicit learning. We hypothesized that individuals with higher resting RSA coupled with greater RSA withdrawal during implicit learning would demonstrate the most implicit learning, operationalized as better reaction time-based scores on the TLT.

## 2. Method

### 2.1. Participants

Seventy-one undergraduate students (37 females, 34 males) from a mid-Atlantic private university participated in this study. Participants were recruited through introductory psychology classes and received course credit as compensation. Data from two male participants were discarded because their ages (53 and 60 years old) did not warrant classification as a young adult, resulting in a final sample of 69 participants. This final sample had a mean age of 19.62 years ( $SD = 2.20$ ), and its

racial and ethnic composition closely matched that of the university, with 55 participants identifying themselves as White (79.7%), three as Black (4.3%), two as Asian (2.9%), eight as Hispanic or Latino (11.6%), and one as Native Hawaiian or Pacific Islander (1.4%). The university's Institutional Review Board approved all procedures, and the participants provided informed consent prior to administration of any measures.

### 2.2. Procedure

The researcher seated the participant in front of the testing computer and manually adhered nine electrodes to the participant's skin in order to collect data on autonomic activity. The sensors were connected to a Mindware physiological data collection system, and data on the participants' RSA were obtained. The researcher instructed the participant to sit quietly during a five-minute acclimation period and a subsequent three-minute resting baseline assessment. Then the participant completed a measure of implicit learning, the Triplets Learning Task (TLT; Howard et al., 2008), followed immediately by a two-minute TLT recognition test, described in detail by Howard et al. (2008), to determine if learning was truly implicit. Upon completion, participants were debriefed and received compensation for their time.

### 2.3. Measures

#### 2.3.1. Triplets Learning Task (TLT)

Participants completed the TLT (Howard et al., 2008), a task used to assess implicit probabilistic associative learning in both younger and older adults (e.g., Simon et al., 2012). Individuals viewed a single row of four empty circles on the computer screen and observed events (i.e., a circle filling in red or green) occurring on each trial. Each trial was comprised of a three-event sequence, or a “triplet”, consisting of two consecutive red “cues” and a green “target” event, as depicted in Fig. 1.

Participants were instructed to observe the first two cue events without responding and to press a key corresponding to the location of the target event. Four buttons on the computer keyboard were used for responding with the middle and index finger of each hand (“z”, “x”, “,”, and “/” corresponding to the four circle locations in left-to-right order, respectively). Fig. 1 provides a detailed depiction of the timing on each trial of the TLT. Reaction time (RT) was recorded (in milliseconds) from the presentation of the target event to the participant's initial response. The target remained on the screen for a fixed amount of time before disappearing. Then an empty row of circles was displayed for 650 ms until the next trial began. Unbeknownst to participants, the location of the first cue predicted one of the four target locations on 80% of the trials (*high-probability triplet*) and was followed by one of the other three target locations on 20% of the trials (*low-probability triplet*). The second cue was always randomly selected, thereby creating a second-order probabilistic relationship between the first cue event and the target event. All 64 possible triplets were presented across the trials of the task, with the six unique combinations of cue-target mappings counterbalanced across the sample. Participants were instructed to respond as quickly and accurately as possible to the location of the green circle (target) on each trial.

Participants performed two successive sessions, each containing ten blocks of 50 trials for a total of 1000 trials per person, and so they were encouraged to rest between blocks for no > 30 s to avoid fatigue. Following Simon et al. (2010), end-of-block feedback was provided to guide participants toward an overall accuracy level of 92%. The triplet type effect (TTE)—the average difference in RT to low-probability and high-probability triplets—was calculated for each participant and was used as the indicator of implicit learning in subsequent analyses (Stillman et al., 2014). Immediately after completion of the TLT, explicit awareness was probed using a sensitive recognition test (Howard et al., 2008), during which participants observed 64 triplets in a random

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