EMOTIONAL STATE AFFECTS GAIT INITIATION IN INDIVIDUALS WITH PARKINSON DISEASE

By

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A DISSERTATION PRESENTED TO THE GRADUATE SCHOOL OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

UNIVERSITY OF FLORIDA

2010
To my family, for all their prayers and support
ACKNOWLEDGMENTS

I would first like to thank God for the abilities that I have been granted and for the people he has placed in my life which has helped me to complete this journey.

I would like to thank my mom and dad for their continued support and unconditional love throughout my life, their belief in me has enabled me to be the person I am today. My sister and brother, Lori and Brian, for their friendship and love, and my grandma, Marcella for her constant support and faith in me.

I would like to thank my mentor, Dr. Christopher Janelle for his continual confidence in me, as well as his wisdom and willingness to guide me not only through this dissertation process, but also in my academic and professional development.

I would like to acknowledge the committee for their hard work and assistance in the development and completion of this project. I would like to thank Dr. Chris Hass for his excellent guidance and support in my doctoral career and this project. I thank Dr. James Cauraugh for his continued guidance, insight, and support in helping me to create this project. I thank Dr. Dawn Bowers for her helping me fine tune this topic and for her consistently positive attitude in this journey.

I would like to thank Steve Coombes for all of his help and guidance, especially in the early stages of doctoral years. I would like to acknowledge Jessica Joyner, Adam Field, Candice Langdon, and Anastasia Jdanova for helping run subjects through the experiment and for the abundant amount of time spent processing data.

Finally, I would like to thank my new husband, Keith Naugle. You bring a smile to my face every day. Thank you for your patience, understanding, and love throughout my doctoral career. You are a wonderful reminder of what life is all about!
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EMOTIONAL STATE AFFECTS GAIT INITIATION IN INDIVIDUALS WITH PARKINSON DISEASE

By

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August, 2010

Chair: Christopher Janelle
Major: Health and Human Performance

Individuals with Parkinson disease (PD) experience postural instability and difficulty initiating gait, which are often highly disabling and not effectively treated by current pharmacological or surgical options. A pressing need exists to develop novel complimentary therapeutic strategies to treat these disabling gait disturbances. The purpose of the present study was to determine the impact of emotional state on gait initiation in persons with PD and healthy older adults. Following the presentation of pictures that are known to elicit specific emotional responses, participants initiated gait and continued to walk for several steps at their normal pace. Reaction time, the displacement and velocity of the COP trajectory during the preparatory postural adjustments, and length and velocity of the first two steps were measured. Analysis of the gait initiation measures revealed that exposure to (1) threatening pictures speeded the initiation of gait for PD patients and healthy older adults, (2) pleasant emotional pictures (erotic and happy people) facilitated the anticipatory postural adjustments of gait initiation for PD patients and healthy older adults as evidenced by greater displacement and velocity of the COP movement, and (3) emotional pictures modulated gait initiation parameters in PD patients to the same degree as healthy older adults.
Collectively, these findings hold significant implications for the development of emotion-based interventions designed to maximize improvements in gait initiation for individuals with PD.
CHAPTER 1
INTRODUCTION

Parkinson disease (PD) is a progressive neurodegenerative disease of the basal ganglia characterized by debilitating motor symptoms and emotional dysfunction. PD is the second most common degenerative disorder (behind Alzheimer’s) and currently affects approximately 1.5 million individuals in the U.S. with 70,000 new cases diagnosed each year (Orr, Rowe, & Halliday, 2002; Hampton, JAMA, 2005). The cardinal motor symptoms of PD include bradykinesia, tremor, rigidity, postural instability and gait dysfunction. Most motor symptoms of PD are driven by nigrostriatal dopamine depletion which causes a cascade of alterations in all components of the basal ganglia functional circuitry (Pahwa & Lyons, 2007). Suffers of PD incur additional countless and measureless costs in terms of functional impairments that permeate and interfere with virtually every facet of daily living.

Despite their benefits, current pharmacological and surgical therapies for patients with PD are limited in their ability to adequately treat postural instability and gait difficulties (Sethi, 2008; Rodriguez-Oroz, Obeso, Lang, Houeto Pollack, Rehcrona, et al., 2005). Furthermore, gait problems are arguably one of the largest unmet needs in the symptomatic treatment of PD (Pahwa & Lyons, 2007). The high and rising prevalence of PD coupled with the lack of adequate treatment for gait deficits in PD, necessitate the development of novel and cost effective interventions for locomotor dysfunction. Given that recent evidence has demonstrated that pleasant emotional states facilitate the initiation of gait in healthy individuals (Gamble, Joyner, Coombes, Hass, & Janelle, in review), manipulating emotional state may be an efficacious strategy to enhance gait initiation parameters in persons with PD. Thus, the primary goal of this
project was to delineate whether and how emotional manipulations would alter gait initiation in persons with PD.

**Posture and Gait Performance in PD**

Gait initiation, the phase between motionless standing and rhythmic walking, requires effective balance control as one moves from stable balance to continuously unstable gait (Halliday, Gai, Blessing, & Geffen, 1990). Prior to the initiation of the stepping movement, anticipatory postural adjustments (APAs) decouple the center of mass (COM) and the net center of pressure (COP). These postural adjustments include a series of muscle activations and changes in ground reaction forces that move the net center of pressure backward and laterally over the swing limb to move the net COM forward over the stance limb (APA phase) (Crenna, Frigo, Giovannini, & Piccolo, 1990; Massion, 1992). This backward shift produces the forward momentum needed to initiate gait. The lateral shift of the COP towards the swing limb propels the COM toward the stance limb, producing the stance side momentum needed to initiate gait (Polcyn, Lipsitz, Kerrigan, & Collins, 1998). A subsequent and quick medial (from swing limb to stance limb) shift of the COP continues to accelerate the COM forward and away from the stance limb (weight shift phase) allowing the swing limb to be unloaded before stepping (Jian, Einter, Ishac, & Gilchrist, 1993). Finally, the COP moves anteriorly until toe-off of the initial stance limb (locomotor phase). Execution of the first step begins when weight has been transferred to the stance limb (Crenna et al., 1990).

The initiation of gait is regulated in parallel by two circuits involving the basal ganglia: 1) basal ganglia – thalamocortical loop, and 2) basal ganglia – brainstem system. The basal ganglia-thalamocortical loop controls the initiation of gait via GABAergic basal ganglia output to the motor cortices through the thalamus. Basal
ganglia output to the supplementary motor area (SMA) likely contributes to the
generation of the APAs, and in particular, the timing of the APA’s (Jacobs, Lou,
Kraakevik, & Horak, 2009). Basal ganglia output to the primary motor cortex plays a
greater role in the execution of the first and second steps (Massion, 1992). Studies on
rats have demonstrated that GABAergic projections from the substantia nigra pars
reticulate (SNr) to the brainstem, and in particular the pedunculopontine nucleus (PPN),
are also important in the initiation of gait (Takakusaki, Habaguchi, Ohtinata-Sugimoto,
Saitoh & Sakamoto, 2003; Takakusaki, Saitoh, Harada, & Kashiwayanagi, 2004; Nandi,
Jenkinson, Stein, & Aziz, 2009).

Difficulty initiating gait typically emerges in PD when patients begin to suffer from
postural instability, which progressively appears at the later stages of the disease. The
dopaminergic denervation of the striatum causes over-activity of the GABAergic output
to the thalamus and brainstem, resulting in increased inhibitory control over the basal
ganglia-thalamocortical loop and the basal ganglia-brainstem system (Takakusaki,
Tomita, & Yano, 2008). Excessive inhibition of thalamocortical projections thereby leads
to defective activation of the motor cortical areas controlling gait initiation (i.e., SMA,
primary motor cortex). Additionally, excessive inhibition of the PPN and other structures
in the brainstem critical for gait initiation (i.e., midbrain locomotor region) contribute to
gait failure.

Abnormalities in the circuitry of gait in PD result in inefficient anticipatory postural
adjustments as evidenced by increased movement preparation time, and decreased
velocity and magnitude of the COP displacements (Burleigh-Jacobs, Horak, Nutt,
Obeso, 1997; Crenna et al., 1990; Halliday et al., 1998). In particular, the initial posterior
and lateral COP movement toward the swing foot during the APAs is reduced and slower in persons with PD. Additionally, the initial steps of persons with PD are characterized by reduced step length and velocity compared to age-matched controls (Crenna et al., 1990). Collectively, research has shown that gait initiation parameters in persons with PD (relative to healthy controls) are smaller, slower, and less forceful. As the disease progresses, these gait abnormalities become more pronounced, limiting quality of life (Morris, Iansek, Smithson, & Huxham, 2000).

Pharmacological interventions typically involve the administration of levodopa or dopamine agonists which alleviate motor symptoms by normalizing dopamine levels (Sethi, 2008). While some symptoms of gait disturbance in PD respond to standard anti-parkinsonian medication, postural symptoms and akinesia are often minimally improved or even exacerbated by levodopa therapy (Pullman, Watts, Juncos, Chase, & Sanes, 1998; Starkstein, Esteguy, Berthier, Garcia, & Leiguarda, 1989). The high and rising prevalence of PD coupled with the lack of adequate treatment for gait deficits in PD necessitates the development of novel and cost effective interventions designed to optimize motor therapy for locomotor dysfunction in PD.

**Emotion Deficits in PD**

The nigrostriatal neuronal degeneration in PD causes dysfunction not only in motor circuits, but also in limbic pathways (e.g., mesocorticolimbic dopaminergic pathway). Additionally, individuals with PD exhibit pathological changes in structures of limbic circuits including the amygdala and ventral tegmental area (Harding, Stimson, Henderson, & Halliday, 2002; German, Manaye, & Smith, 1989; Uhl, Hedreen, & Price, 1985). Not surprisingly then, PD is increasingly linked with emotional dysfunction. For example, individuals with PD exhibit impairments in affective recognition as indexed by
both facial expressions and prosodic production (Smith, Smith, & Ellgring, 1996; Caektekeke, Jennekens-Schinkel, van den Linde, Buruma, & Ross, 1991). Deficits in perception of emotional expression and greater symptoms of depression, anxiety, and apathy also characterize PD (McDonald, Richard, & DeLong, 2003; Slaughter, Slaughter, Nichols, Holmes, & Martens, 2001). Importantly, these emotional symptoms in PD represent a distinct deficit in PD and are not just a product of motor dysfunction.

Research has also revealed that individuals with PD exhibit reduced psychophysiological reactivity to aversive stimuli. Bowers and colleagues demonstrated that individuals with PD while “on” medication exhibit blunted startle eye blink magnitude to aversive pictures compared to healthy controls, while startle reactivity to pleasant pictures was similar to that of healthy controls (Bowers, Miller, Mikos, et al., 2006). Miller et al., (2009) later qualified these findings by revealing a lack of startle potentiation to only a specific subcategory of aversive pictures; namely, mutilations. Similar startle reactivity in response to attack, contamination, pleasant, and neutral pictures was observed among control and PD patients. However, further statistical analysis indicated that the mutilation pictures may have been the only category of aversive pictures that were sufficiently arousing to detect a deficit in emotional reactivity in PD patients. The basis of this reactivity is unknown, but may be linked to disease-related dopamine depletion and the subsequent inhibition of the amygdala in response to stress-inducing stimuli. While empirical investigations have examined how emotion alters involuntary movement (i.e., startle eye blink) in PD, researchers have yet to explore whether emotion modulates voluntary movements of persons with PD, and whether such modulation is similar to that observed in healthy individuals. The current
project will be the first investigation of how emotion impacts voluntary movement in persons with Parkinson disease.

**Emotion and Motor Function: An Integrated Approach**

A growing body of literature supports the long held notion that human emotions have evolved as fundamental action dispositions, facilitating behaviors essential for survival (Frijda, 2009; Frijda, Kuipers, & ter Schure, 1989; Lang, 1995). As such, emotions motivate behavioral responses to approach pleasant and avoid unpleasant stimuli and situations. In general, unpleasant emotions activate defensive circuitry and prime avoidance behaviors, whereas pleasant emotions activate appetitive circuits that prime approach behaviors. Importantly, however, accumulating evidence has revealed that not all aversive stimuli facilitate avoidance-related behavior. For example, fearful facial expressions, rated as appearing highly submissive and as equally affiliative as happy expressions (Hess, Blairy, & Kleck, 2000), have been shown to facilitate approach-related upper extremity pulling movements (Marsh, Ambady, & Kleck, 2005). Additionally, although fear is generally associated with a withdrawal response (i.e., “flight”), it can also elicit approach to safe places or an approach-related “fight” response to threatening stimuli (Blanchard & Blanchard, 1994). Finally, several lines of research have shown that anger, although negative in valence, elicits approach motivational tendencies (See Carver & Harmon-Jones, 2009 for a review). As such, grouping of affective stimuli into specific categories (i.e., attack, mutilation), rather than broad valence categories (i.e., unpleasant, pleasant), is essential to a comprehensive understanding of how emotion influences movement. Based on the aforementioned evidence, particularly the Miller et al. (2009) study indicating a possible emotion-specific
reactivity deficit in PD, we utilized the emotion-specific approach in the current project by exploring how the elicitation of discrete emotions influences the initiation of gait.

**Emotion Modulated Movement**

Collectively, behavioral and transcranial magnetic stimulation (TMS) data suggest that emotional stimuli prime or facilitate action. TMS evidence indicates that increases in emotional arousal (intensity) lead to greater primary motor cortex excitability when passively viewing emotional images (Hajcak, Molnar, George, et al., 2007). This finding has been recently expanded and specified by Coombes, Tandonnet et al. (2009) who found increased corticospinal motor tract excitability during the preparation of a voluntary motor action when participants viewed emotional arousing images compared to neutral images. Behavioral evidence demonstrates that emotional state significantly influences parameters underlying single joint and whole body movements. Intense emotional states increase force production on non-directional submaximal sustained movements (i.e., pinch grip: Coombes, Gamble, Cauraugh, & Janelle, 2008), while unpleasant emotional states increase force production on sustained extension movements at maximal exertion (Coombes, Cauraugh, & Janelle, 2006). Additionally, exposure to attack images compared to mutilation, pleasant, and neutral images, has been shown to speed reaction times on ballistic pinch grip and wrist extension movements (Coombes, Higgins, Gamble, Cauraugh, & Janelle, 2009; Coombes, Cauraugh, & Janelle, 2007). Coombes et al. (2007) provided evidence that speeded reaction times in response to threatening images are driven by expedited central processing times that precede the movement. These studies also further support the categorization of affective stimuli into emotion-specific, rather than broad valenced categories when evaluating emotion modulated movement.
Critical to the current proposal, we recently evaluated the influence of emotional state on forward gait initiation in healthy young adults (Gamble et al., in review). Participants initiated gait following the offset of affective stimuli (low and high arousing unpleasant, low and high arousing pleasant, and neutral) and continued to walk toward the location of the presented stimuli for several steps. Viewing highly arousing unpleasant stimuli (i.e., attack images) speeded the initial motor response compared to all other affective stimuli, supporting the notion that threatening cues prime the motor system for action regardless of movement direction. However, the presentation of the pleasant stimuli facilitated the initiation of forward gait as indexed by greater posterior and lateral COP movement toward the swing limb during the anticipatory postural adjustments, as well as greater velocity of the COP shift. Furthermore, the first step was executed with increased velocity following the presentation of pleasant images compared to unpleasant images. These data provided evidence that emotional state systematically alters gait initiation. Moreover, given that forward gait represents a clear approach oriented behavior in this context, the finding that pleasantly valenced emotional pictures facilitated gait is consistent with the notion that affective valence uniquely contributes to movement modulation beyond the initial reaction time. As such, activating emotional circuits may an effective method to optimize the quality of intended movement, particularly for PD patients suffering gait initiation impairment.

**The Integration of Emotion and Motor Processes**

Behavioral and TMS evidence collectively suggests that motor circuits are not segregated from affective processes; indeed such processes are largely desegregated. Based on research involving primates and rodents, Haber and colleagues proposed that emotion can be integrated into the motor circuits via two potential mechanisms involving
the basal ganglia (Haber, 2003; Haber & Calzavara, 2009). First, affective information can be channeled across functional basal ganglia cortical circuits via thalamic relay nuclei linking functionally adjacent frontal cortical areas (limbic → cognitive → motor). Thus, information is channeled in a feedforward manner from the limbic basal ganglia-thalamocortical loop to the cognitive and then motor loop, allowing affective information to shape the final motor output. Secondly, the limbic pathway can influence motor output via the striato-nigro-striatal pathway, in which the affective region of the striatum (i.e., ventral) modulates the motor and more dorsal region of the striatum through midbrain dopamine neurons. Critically, individuals with PD exhibit atypical activation within motor and limbic basal ganglia circuits via loss of dopaminergic neurons in the SN, causing motor and emotional dysfunction. Thus, particularly during “off” states (off DBS and DA therapy) emotion information may not be integrated into the motor system as in healthy individuals. However, during “on” states when standard anti-Parkinsonian pharmacological treatments normalize DA levels, we predict that emotion information will be successfully integrated into the motor system allowing emotional input to impact the quality of intended movements.

In sum, persons with PD exhibit postural instability and difficulty initiating gait, which have highly disabling consequences that are not effectively treated by current pharmacological or surgical options. Research indicates that activating emotional circuits accelerates the initiation and execution of voluntary motor actions, and most importantly, facilitates anticipatory postural adjustments and step execution during forward gait initiation. A high degree of integration is known to exist among circuits involved with the production and regulation of emotion and motor systems, including the
circuits involved with the regulation of gait. However, important questions remain concerning how emotion modulates movement in persons with PD. Given the integration of the emotion and motor circuits, and considering consistent behavioral evidence that emotional state modulates simple and complex movements, we postulate that manipulating emotional conditions may be an efficacious method to improving gait initiation parameters in persons with PD.

The purpose of the proposed project was to determine the impact of emotional state on the quality of gait initiation in persons with PD. Individuals with PD and healthy aged-matched controls were exposed to attack, mutilation, contamination, erotica, happy people, neutral, and blank pictures. Participants initiated gait at picture offset and continued to walk for several steps at their normal pace. Of specific interest was to determine the extent to which specific emotion categories alter the speed of movement initiation (reaction time), the quality of the postural adjustments during gait initiation (as indexed by COP displacements and velocities), and step execution (as evidenced by the length and velocity of the first and second steps). Comparisons of these dependent measures were made between the PD and control groups after viewing exemplars from the seven picture categories. Additionally, and replicating previous work (Gamble et al., in review), we evaluated the degree of change in gait initiation performance due to each affective category relative to the neutral pictures (i.e., percent change scores). The degree of change under such conditions was also compared across groups. The following hypotheses were offered:
Hypotheses

Reaction Time:

1) Across stimulus conditions, control participants would exhibit faster reaction times on the gait initiation task compared to participants with PD.

2) Exposure to attack pictures would lead to significantly faster reaction times on the gait initiation task compared to all other picture categories for all participants.

3a) If emotion modulates the speed of the initiation of gait in PD patients to the same degree as healthy controls, then no significant differences would exist between control and PD participants for the attack percent change scores.

3b) However, if emotion does not modulate the speed of the initiation of gait in PD patients in the same way as healthy controls, then the attack percent change scores would be significantly smaller (smaller change relative to neutral category) for the PD participants compared to control participants.

COP Trajectory and Step Execution Measures:

4) Compared to PD participants and across all conditions, control participants would exhibit a) greater displacement and velocity of the posterior and lateral COP movement during the APA phase, b) greater displacement and velocity of the medial COP movement during the weight shift phase, c) greater displacement and velocity of the anterior COP movement during the locomotor phase and d) greater length and velocity of the first and second steps.

5) For all participants, exposure to the approach-related categories of erotica and happy people would facilitate forward gait initiation compared to all other categories as evidenced by: a) greater displacement and velocity of the posterior and lateral
movement during the APA phase, b) greater velocity of the medial movement during the weight shift phase, and c) greater length and velocity of the first and second steps.

6a) If approach-related emotions modulate COP movements and step execution in PD patients the same way as healthy controls, then no significant differences would exist between control and PD participants for the erotica and happy people percent change scores.

6b) However, if approach-related emotions do not modulate COP movements and step execution in PD patients in the same way as healthy controls, then the erotica and happy people percent change scores would be significantly smaller for the PD participants compared to control participants.

7) For all participants, exposure to the pure withdrawal-related categories of mutilation and contamination would debilitate forward gait initiation compared to all other categories as evidenced by: a) decreased displacement and velocity of the posterior and lateral movement during the APA phase and b) decreased velocity of the medial movement during the weight shift phase, and c) decreased length and velocity of the first and second steps.

8a) If withdrawal-related emotions modulate COP movements and step execution in PD patients the same way as healthy controls, then no significant differences would exist between control and PD participants for the contamination and mutilation percent change scores.

8b) However, if withdrawal-related emotions do not modulate COP movements and step execution in PD patients in the same way as healthy controls, then the
absolute value of the mutilation and contamination percent change scores would be significantly smaller for the PD participants compared to control participants.
CHAPTER 2
REVIEW OF LITERATURE

Introduction

The purpose of this review is to synthesize relevant literature concerning the integration of emotion and motor function, with a specific focus on gait initiation. An additional objective is to gain a greater understanding of how the brain circuits involved with emotion and movement integration are altered among individuals who have Parkinson disease (PD), a disease with co-morbid emotional and motor deficits. Implications for understanding the disease as well as potential avenues toward developing novel treatments for PD (and other movement and affective disorders) are offered based on careful consideration of the current knowledge base and promising future research directions.

The current chapter represents a focused review of the extant behavioral, neuroanatomical, and physiological basis for understanding the interplay of emotions and motor actions. Comprehensive treatment of this topic required assimilation of diverse and unique bodies of literature, as reflected in the organization of the paper. First, an introduction to Parkinson disease is provided with discussion of the underlying pathophysiological mechanisms of the disease and a review of the most common treatment options. Second, a section on motor function with specific emphasis on gait initiation is presented, including description of the neural circuitry involved and relevant theories of movement planning and control. The section concludes with a discussion of gait deficits in PD and its underlying pathophysiology. Third, information related to the study of emotion is provided, including a review of theoretical perspectives, the circuitry of emotion, and emotion deficits in PD. Fourth, evidence for how emotions modulate
movement, with emphasis on approach and avoidance movements, is elucidated. Current knowledge concerning the neural circuitry integrating emotion and motor function is also addressed. Finally, the implications of how emotion may impact movement for individuals with PD are discussed.

**Parkinson Disease**

Parkinson Disease (PD) is a progressive neurodegenerative disease of the basal ganglia that affects over one million individuals in the United States each year (Van Den Eeden, Tanner, Bernstein et al., 2003). Driven by dopamine depletion within the complex basal ganglia circuitry, persons with PD exhibit debilitating motor symptoms as well as emotional dysfunction. The cardinal motor symptoms of PD include bradykinesia, tremor, rigidity, postural instability, and gait dysfunction. PD is the second most common degenerative disorder after Alzheimers, with an overall incidence of 13.4 per 100,000 (Van Den Eeden et al., 2003; Orr, Rowe, & Halliday, 2002). The incidence of PD dramatically increases for people over 60 years old and with the aging US population, this number is projected to rise significantly in the coming years (Van Den Eeden et al., 2003). Sufferers of PD incur countless and measureless additional costs in terms of functional impairments that permeate and interfere with virtually every facet of daily living.

**Pathophysiology of Parkinson Disease**

PD is characterized by a loss of nigrostriatal neurons in the substantia nigra pars compacta (SNpc) of the basal ganglia (Pahwa & Lyons, 2007). The degeneration of dopaminergic containing neurons results in severe dopaminergic denervation of the striatum and a cascade of subsequent functional changes involving all components of basal ganglia circuitry (Blandini, Nappi, Tassorelli, & Martignoni, 2000). These
pathological changes underlie most motor symptoms of PD, particularly akinesia (i.e., failure or slowness of willed movement) (Rosin et al., 2007). The onset of clinical symptoms is associated with a 50-60% loss of nigrostriatal neurons and a 70% decrease in striatal dopamine concentrations (Bernheimer, Birkmayer, Hornykiewicz, Jellinger, & Seitelberger, 1973). Initially, the surviving neurons increase dopamine synthesis to compensate for the cell loss. However, as the disease progresses and neuronal loss increases the compensatory mechanisms fail and the nigrostriatal neurons lose the ability to appropriately store and release DA (Mouradian, Juncos, Fabbrini, & Chase, 1987). Figure 2-1 demonstrates a schematic view of the internuclear connectivity of the basal ganglia neuronal networks, as well as the changes associated with PD.

The striatum of the basal ganglia relays information from the cerebral cortex to the basal ganglia output nuclei (i.e., GPi and SNr) via direct and indirect pathways (Sohn & Hallet, 2005; Blandini, Nappi, Tassorelli, & Martignoni, 2000). In the direct pathway the striatum projects a subset of GABAergic neurons, expressing D1 dopaminergic receptors, to the GPi and SNr. Thus, the direct pathway inhibits the GABAergic inhibitory output of the GPi/SNr, resulting in the subsequent disinhibition of thalamic and brainstem nuclei. In the indirect pathway the striatum projects a subset of GABAergic neurons, expressing D2 dopaminergic receptors, to the GPe. GABAergic inhibitory neurons of the GPe project to the STN, which sends excitatory glutaminergic input to the GPi and SNr. Thus, the indirect pathway increases the inhibitory output of the GPi/SNr to the thalamus and brainstem via the inhibition of GPe and subsequent disinhibition of the STN. Collectively, the net output of the basal ganglia is regulated by
the indirect (i.e., increases the inhibitory output of GPi/SNr) and direct pathways (i.e., inhibits the inhibitory output of GPi/SNr). Balanced activity between these two pathways is essential for the control of voluntary movement. As shown in Figure 1, PD is characterized by an imbalance of activity resulting from dopamine depletion of the SNc, which decreases the activity of the direct pathway while increasing the activity of the indirect pathway. This imbalance produces excessive inhibition of the thalamocortical and brainstem motor systems, ultimately causing movement dysfunction.

Researchers and clinicians now accept that the pathology associated with PD extends beyond nigrostriatal dopamine depletion. PD has been associated with the neurodegeneration of serotonin and norepinephrine pathways in limbic circuits, and nerve cells in the dorsal motor nucleus of the vagus, the pedunculopontine nucleus (PPN), olfactory region, ventral tegmental area (VTA) and hippocampus (German, Manaye, & Smith, 1989; Pahapill & Lozano, 2000; Remy, Doder, & Lees, 2005; Sethi, 2008). Neurodegeneration in these nondopaminergic regions likely accounts for the non-motor features of PD, including neuropsychiatric symptoms (i.e., affective disorders, dementia, hallucinations), sleep disorders, autonomic symptoms (i.e., urinary disturbances, sexual dysfunction), and sensory symptoms (i.e., pain, olfactory symptoms) (Sethi, 2008).

**Treatment for PD**

Multiple treatment options currently exist for the management of PD, however, there is no cure for the disease and no treatment alleviates all symptoms. A brief overview of the most common pharmacological and surgical approaches to the treatment of PD is presented next.
Pharmacological treatments

**Levodopa.** For the past 40 years Levodopa (L-3,4-dihydroxyphenylalanine) has been the mainstay of symptomatic therapy for PD (Sethi, 2008). Levodopa, a metabolic precursor of the neurotransmitter dopamine, traverses the blood brain barrier normalizing dopamine levels. Research has shown that levodopa alleviates symptoms at all stages of the disease and does not result in tolerance over time (Markham & Diamond, 1981, 1986). The symptoms of bradykinesia (i.e., slowness of movement) and rigidity show the best response to this pharmacological treatment. Although providing benefits to virtually all patients, levodopa does not stop the progression of the disease and presents with several shortcomings. First, the duration of the medication action becomes progressively shorter with chronic usage (Muenter & Tyce, 1971). Additionally, chronic usage is associated with adverse effects, such as motor fluctuations and dyskinesia (i.e., the impairment of voluntary movements resulting from jerky motions) (Pahwa & Lyons, 2007). Furthermore, levodopa has little or no effect on certain motor (i.e., freezing of gait and postural instability) and non-motor symptoms (i.e., sleep disturbances, cognition, and mood), which likely arise from the degeneration of nondopaminergic systems (Sethi, 2008). Levodopa is typically prescribed with adjunctive therapies, such as dopamine agonists.

**Dopamine Agonists.** Dopamine agonists were first used to treat PD in the late 1970’s as an adjunct therapy to levodopa (Birkmayer & Hornykiewicz, 1961). In the last 30 years, DA agonists have been used to improve motor symptoms at all stages of PD, both as an adjunct therapy and as monotherapy. In contrast to levodopa, this medication provides therapeutic benefits while delaying the development of dyskinesia and motor fluctuations (Brannan, Prikhojan, Yahr, 1997; Cedarbaum, Leger, Reches, &
DA agonists work by activating striatal D2 dopamine receptors, thereby normalizing the activity of the indirect pathway of the basal ganglia. Similar to levodopa, DA agonists fail to alleviate symptoms resulting from nondopaminergic pathology. Several side effects include nausea, sleepiness, confusion, orthostatic hypotension, and hallucinations (Poewe, 2005).

**Surgical treatments - deep brain stimulation**

Deep brain stimulation did not become a popular treatment for PD until the late 1980s. This neurosurgical treatment involves the surgical implantation of a battery operated neurostimulator, which is used to deliver a steady pulse of mild electrical signals to targeted areas in the brain (Pahwa & Lyons, 2007). The electrical pulses are thought to block any abnormal firing of neurons. DBS in PD patients typically targets either the ventral intermediate nucleus of the thalamus, GPi, or STN (Benabid, LeBas, Grand, Krack, Chabardes, Fraix et al., 2005). DBS of the ventral intermediate nucleus is the preferred target to treat the medication resistant tremor. Studies have reported that DBS of this target significantly reduces Parkinsonism tremor in 60-95% of PD patients receiving the surgery (Benabid, Pollack, Gervason,1991; Koller, Pahwa, Busenbark, Hubble, Wilkinson, Lang et al., 1997). While tremor improves, other symptoms continue to progress (Hubble et al., 1997; Pahwa et al., 2006). Thus, DBS of the thalamus is only used for PD patients whose primary disability is caused by tremor. DBS targeting the GPi and STN have been shown to improve all the cardinal symptoms of PD, as well as levodopa-induced dyskinesia. Additionally, research has documented the long term benefits of STN DBS (Pahwa, Wilkinson, Overman, & Lyons, 2003; Rodriguez-Oroz, Obeso, Lang, Houeto, Pollak, Rehcrona, et al., 2005). For example Rodriguez-Oroz et al., conducting the first worldwide multicenter trial of DBS in PD, assessed 69 PD...
patients 3-4 years following bilateral DBS surgery (STN = 49, GPi = 20). At the 3-4 year follow-up, patients who received STN DBS showed a 50% improvement on the “off” medication scores of the Unified Parkinson’s Disease Rating Scale motor part (UPDRS-III), while GPi DBS induced a 39% improvement. Stimulation of both targets also improved the cardinal features of PD (except postural instability), activities of daily living (ADL), and prolonged the time “on” medication without experiencing dyskinesia. However, comparison of the improvement induced by STN stimulation at 1 year compared to the 3-4 year follow-up demonstrated a significant worsening in both the “off” and “on” medication motor states of the UPDRS-III, ADLs, speech, postural stability, and gait. Similarly, comparison between improvement induced by GPi stimulation at 1 year and 3-4 years revealed a significant worsening in the “on” medication states on the UPDRS-III, gait, and ADLs. Thus, while STN and GPi DBS surgery appear promising for improving motor symptoms in PD, the beneficial effects on gait and postural stability do not appear to persist long-term.

Although DBS is considered a relatively safe procedure, adverse effects usually arise from one of three complications: surgical, hardware-related, or stimulation (Pahwa & Lyons, 2007). Surgical complications may include hemorrhage, seizures, infections, and misplaced leads (electrodes). Such complications usually occur within 30 days post surgery and occur in less than 5% of all patients. Hardware-related complications include electrode and extension wire (i.e., connects electrode to neurostimulator) failure and often require repeated surgeries. Stimulation complications depend on the exact location of the lead and intensity of stimulation and may include double vision, dystonic
posturing (i.e., sustained unnatural positioning of a body part with a rotational component), depression, mood changes, pain, and limb and facial muscle spasms.

**Physical therapy**

A variety of physical therapy approaches have been used to treat PD patients. The focus of therapy is largely directed by the stage of the disease. Patients with mild to moderate PD are usually taught exercises designed to delay or prevent the aggravation of motor impairment (Lugassy & Gracies, 2005). Additionally, a major goal of physical therapy is to improve postural control and reduce the frequency of falls (Pelissier & Perennou, 2000). These exercise techniques may include resistance training, attentional strategies and sensory cueing, active mobilization and stretching, as well as treadmill training. Research has shown that lower limb resistance training in PD patients improves balance and gait by increasing lower limb muscle strength (Hirsch, Toole, Maitland, & Rider, 2003; Scandalis, Bosak, Berliner, Helman, & Wells, 2001). Additionally, an increasingly prevalent technique in physical therapy is the use of external visual or auditory cues to enhance performance. For example, a number of studies have shown that horizontal floor markers used as visual cues normalize PD patients stride length, velocity, and cadence (Morris, Iansek, Matyas, & Summers, 1996). In advanced PD, patients who experience freezing episodes can be taught to replace the deficient internal motor cues normally provided by the basal ganglia with external auditory, visual, or proprioceptive cues to initiate movement (Morris, Iansek, & Kirkwood, 1995). Research is needed to investigate the long-term benefits of physical therapy and the most effective regimens for improving motor symptoms.

In sum, current pharmacological and surgical therapies for patients with PD have shown clear but limited benefits as treatments for postural instability and gait difficulties.
Gait symptoms are disabling and contribute to the progression towards loss of independence and ultimate confinement to a wheelchair. A pressing need therefore exists to develop novel complimentary therapeutic strategies to treat disabling gait disturbances. Additionally, the high prevalence of non-motor symptoms, such as depression and apathy, often complicate therapy and reduce overall quality of life. A high degree of integration is known to exist among neural circuits involved with the production and regulation of human emotion and motor systems, including those involved with the regulation of gait (Haber, 2003; Haber & Calzavara, 2009; McFarland & Haber, 2002). Given the integration of emotion and motor circuits along with recent behavioral evidence demonstrating the impact of emotion on movement (e.g., Coombes, Cauraugh, & Janelle, 2007; Coombes, Gamble, Cauraugh, & Janelle, 2008; Gamble, Joyner, Coombes, Hass, & Janelle, 2009), manipulation of emotion may be a viable strategy for improving movement in individuals with PD. This review will attempt to provide a foundation from which to advance these efforts and establish clear links between emotion and motor function by presenting a comprehensive account of the processes involved with human movement and emotion. As a basis for discussion of how emotions influence motor function, traditional and contemporary theoretical approaches to explaining the mechanisms that underlie motor execution are reviewed next.

**Overview of Movement**

The purpose of this section is to first provide an introduction to the theoretical perspectives that have guided the field of motor behavior. Following the review of general motor theory, the focus will narrow to discussion of a specific movement, gait.
initiation. The neural mechanisms underlying gait initiation will be detailed followed by a review of gait dysfunction in PD.

**Theories of Motor Control**

Two schools of thought have dominated the motor learning and control literature (Newell, 2003). The cognitive (indirect) school of thought interprets human motor behavior based on the ideas of schema theory and motor programs. An ecological (direct) school of thought arose as a competing theory to the cognitive approaches and views motor behavior through a dynamical systems framework. The dominant theories of both perspectives will be discussed next.

**Cognitive theories of movement control and coordination**

The cognitive approach to understanding motor behavior views the mind largely as a computer analogue, able to form symbolic representations in the central nervous system (CNS) during goal-directed behavior. The early cognitive-phenomenological approaches to understanding motor behavior (e.g., Closed Loop Theory, Schema Theory) were concerned with the development of laws and principles of motor behavior, without regard for the underlying brain circuitry that regulates emergent behaviors. These theories will be reviewed first, followed by discussion of a more recent structural model of motor action which distinguishes the neural substrates underlying motor planning and motor control.

**William James’ (1890) Response Chaining Hypothesis.** One of the earliest theories of motor control was proposed by psychologist William James (James, 1890). James’ theory was driven by the observation that control of skilled movement did not require much conscious involvement. James hypothesized that while attention is needed to initiation an action, the remainder of the movement is controlled
“automatically” by the performer. According to the *Response-chaining Hypothesis*, movement is initiated by internal or external signals that cause a muscle contraction. The movement produced by the muscle contraction generates sensory information, or response-produced feedback. As demonstrated in Figure 2-2, feedback triggers the 2nd muscle contraction, which again produces response-produced feedback which triggers the third contraction. This pattern continues until the performer produces all the muscle contractions needed to complete the movement. James’ Response Chaining Hypothesis was disproved by the many studies on deafferented animals (Polit & Bizzi, 1978; Taub & Berman, 1968) and humans (Kelso, 1977; Kelso, Holt, & Flatt, 1980; Smith, Roberts, & Atkins, 1972), demonstrating that movements can occur in the absence of any movement produced feedback. Additionally, research on locomotion and gait revealed how movement can occur without sensory feedback (i.e., central pattern generators).

**Adams Closed Loop Theory (1970).** Adams’ Closed Loop theory proposed the existence of two structures (i.e., a memory trace and a perceptual trace) which produce and regulate movements through open and closed-loop processes (Adams, 1971). Initiated by the volition of the individual, a memory trace acts in an open-loop fashion by selecting and initiating the desired movement. The memory trace is a central representation of the sensory feedback from a previously successfully executed movement of the same type. In essence, the memory trace acts as a motor program to initiate movement in the absence of feedback. After the response is executed, a perceptual trace evaluates the correctness of the motor response as executed by the memory trace. As such, the perceptual trace provides a reference as how to adjust the
next movement based on the knowledge of results that have been received. However, response-produced feedback is often too slow to guide the control of rapid movement. Thus, Adams’ theory was limited by its inability to explain rapid and discrete movements.

**Motor Program Concept (1975).** Originally dating back to the thinking of James (1890), Lashley (1917), Keele (1968), and Keele and Summers (1975), the motor program concept applied a computer metaphor to the control and learning of human motor behavior. According to this open-loop view, central structures or programs represent the desired characteristics of a movement and when activated, these abstract representations produce the movement with minimal regard for sensory information. Only after sufficient time has passed can central information processing mechanisms modify the movement. Early studies of the motor program concept primarily investigated rapid discrete motor responses (< 250 ms) in an effort to reduce any feedback corrections that would taint the results. Two major challenges for motor control and learning theorists arose from Adams’s theory and the Motor Program concept of the early 1970’s (Schmidt, 2003): 1) the storage problem for memory of movement and 2) the novelty problem. The motor program concept, as well as Adams’ notion of a memory trace, assumed that a program or trace was needed for every separate movement that could be performed. The storage problem held that the limited memory capacity of the human central nervous system was not capable of storing the vast amount of movement representational details for all the actions of an individual over a lifetime. The novelty problem highlighted the inability of current theoretical approaches
to account for how humans produce a movement that has not been previously performed. Schmidt developed Schema Theory to address these limitations.

**Schema Theory (1975).** Borrowing heavily from both Adams’ Closed-Loop theory and the motor program concept, Schmidt (1975) developed a theory designed to account for how humans produce and store the numerous movement variations capable of being performed. In contrast to the previous theories, Schema theory could also explain the control and learning of rapid and slow movements, discrete movements, movements with and without visual feedback, and tracking movements.

A central tenet of schema theory is that two independent memory representations control programmed movements. First, an abstract memory structure, called the general motor program (GMP), is capable of transforming stored codes into patterns of movement. The GMP is the basis for producing motor responses within a movement class that share invariant characteristics (i.e., sequence of submovements, relative timing, and relative force). The second memory representation, the parameters, specifies the variant characteristics of the movement before execution (i.e., absolute time, absolute force, and muscle selection). The major support for the GMP and parameters as separate memory states originated from studies showing that the structure of the movement remains invariant while the temporal, spatial, and force dimensions of the movement vary (Gentner, 1987; Schmidt, 1985; Wright & Shea, 2001; Wulf & Schmidt, 1989; Wulf, Schmidt, & Deubel, 1993). The GMP was an upgrade of the motor program concept and the most important idea distinguishing Schema theory from the Closed-loop theory. A key feature of the GMP concept is that the programs are generalized, so that humans can execute many different movements with the same
program and generate novel movements through the selection of parameters that have not been previously used. Thus, Schmidt’s idea of the GMP reduces both the storage and novelty problems of motor control and learning. However, Schema theory is limited by its failure to address how GMPs are acquired or modified; the existence of GMPs is merely assumed with no neurological basis for the assumption.

Schmidt also proposed that humans develop schema rules through practice and experience across a lifetime. A schema rule is the relationship between the movement outcomes of past attempts and the parameters selected on those attempts. Schema rules can be categorized into recall and recognition schemas. A recall schema describes the relationship between the parameters selected for a motor program on each movement trial and the achieved movement outcome. Essentially, recall schema is used to scale movements governed by the GMP across one or more superficial dimensions (e.g., speed, size, muscles used) and by the allocation of movement parameters (e.g., absolute time or force). Recognition schema is a rule that describes how past sensory consequences caused by running the motor program are related to the outcomes of the program. Schema theory predicts that variable practice within a class of movements (i.e., practice in parameter selection for the GMP) facilitates the development of schema rules, and thereby enhances the ability to select novel parameters in future situations.

Although still one of the primary cognitive accounts of human motor control and learning, schema theory is deficient in a number of ways. One major problem of schema theory is the lack of explanation for how GMPs are acquired or modified. Rather, the theory focuses primarily on how individuals learn to scale GMPs. Additional problems
have arisen from the GMP concept including 1) evidence disproving the idea that relative force is invariant in the GMP and 2) studies showing that the GMP cannot account for movements involving gravity (e.g., Schmidt & McGown, 1980). Finally, as notions of schema theory were based primarily on studies of discrete actions, continuous actions (e.g., juggling) relying on an individual’s interactions with the environment are beyond the scope of the theory (Schmidt, 2003). Thus, while schema theory has provided important insights into certain aspects of motor control and learning, modification of some of the basic tenets is needed to account for a greater database of empirical findings.

**Planning – Control Model.** Glover (2004) proposed a model of human action production which dichotomized human motor behavior into motor planning and motor control processes. Evidence from brain-damaged samples (Grea et al., 2002; Jakobson, Archibald, Carey, & Goodale, 1991; Jeannerod, 1986) and brain imaging studies (Desmurget et al., 2001; Grafton, Mazziotta, Woods, & Phelps, 1992; Krams, Rushworth, Deiber, Frackowiak, & Passingham, 1998) link the planning and control stages of action with distinct visual representations in the inferior parietal lobe (IPL) and the superior parietal lobe (SPL), respectively. The planning stage generally takes place before movement initiation with the aim of selecting and initiating an adaptive motor program, while the control stage guides the execution of the action with the focus of online correction of the spatial parameters of the movement.

Glover contends that the planning of a movement corresponds to brain activity in the inferior parietal lobe (IPL). Figure 2-3 gives a schematic illustration of the motor planning process. The initialization of motor planning begins with the descention of
visual, cognitive, and sensory information from three separate regions of the brain to the IPL for integration. Visual information utilized for planning (i.e., spatial and non-spatial characteristics of the actor and target, and the visual context surrounding the target) travels to the IPL via the temporal lobe and a third visual stream. The frontal lobes provide information on the overarching goals of the action and make decisions of executive control (cognitive input), while the somatosensory association areas of the brain supply proprioceptive input to the IPL. The integration of these three sources of information guides the IPL’s selection of a kinematic motor plan from the frontal lobes, basal ganglia, and subcortical structures for the ensuing action. The selected motor program descends from the frontal lobes and subcortex to the peripheral nervous system initiating the movement. Ultimately, the planning system is responsible for selecting the target and the macroscopic aspects of the movement and determining all movement parameters relating to the non-spatial target characteristics, the initial movement parameters relating to spatial characteristics, and the timing of movements. As the movement progresses, an efference copy of the plan is transmitted from the IPL to the superior parietal lobe (SPL) and cerebellum where the control system gradually takes over the movement. However, in circumstances in which the control system’s other sources of information (i.e., visual feedback and proprioceptive input) are removed or missing, the action will be executed according to the efference copy provided by the IPL and thus entirely as planned without the benefit of online adjustments.

The gradual crossover of the planning stage to the control stage allows for smooth corrections of the movement. Through feedback (visual and proprioceptive input) and feedforward (efference copy) mechanisms, the control system monitors and
adjusts the motor programs in flight (See Figure 2-4). A transient visual representation (via the dorsal stream) integrates with proprioception and the efference copy in the superior parietal lobe (SPL) to produce the online corrections. According to Glover’s theory, the control system, in contrast to the planning system, operates outside of conscious awareness and is confined to utilizing the spatial parameters of the target to guide online adjustments. However, several studies (e.g., Brenner & Smeets, 1997) provide evidence indicating that control processes may not be completely immune to the interference of the surrounding visual context of the target and cognitive processes.

According to Glover’s model, errors in movement arise from either how the movement was planned, during the execution of the plan (i.e., noise in the neuromuscular system), or from unanticipated changes in spatial characteristics. Because the control system often corrects for errors in planning, control processes routinely contribute to errors in action production. Furthermore, the accuracy of longer duration movements, which provide visual and proprioceptive feedback loops more time to operate, primarily rely upon the control system. Indeed, removal or alteration of any one of the control system’s primary sources of information may alter the success/outcome of the intended movement.

The primary weakness of Glover’s planning-control model appears to be its oversimplistic nature in the distinction between motor planning and control processes. Recent evidence indicates Glover’s assertion that motor planning is mediated by the inferior parietal lobe (IPL) and motor control is mediated by the superior parietal lobe (SPL) is too strong and schematic (Battaglini, Naranjo, & Brovelli, 2002). Similarly, not all movements can be neatly partitioned into planning and control processes. For
example, as will be discussed later in the Movement section of this review, the initiation of gait involves a preparatory and execution component, both of which likely involve a combination of planning and control processes. In addition, the mechanisms underlying planning may be much more diverse than suggested by Glover. Based on evidence from models of deficits in apraxia (i.e., the inability to execute complex coordinated movements without muscular or sensory impairments), Longo & Bertenthal (2004) suggested that in complex, ecological situations planning will have goals of both selecting adaptive motor programs (as stated by Glover) and inhibiting non-adaptive motor programs. Despite the weaknesses of the model, Glover’s distinction between motor planning and motor control currently provides an attractive conceptual framework for understanding and analyzing human action production.

**Ecological theories of movement control and coordination**

The ecological approach emerged from efforts to alleviate the limitations within the cognitive approach to motor control. These limitations include: 1) the arbitrary nature of the description of the abstract representations, 2) the assumption of performer-environment independence and the resulting focus on the elements of movement outcome rather than on the intrinsic dynamics of the constraints that guide dynamical organization to movement outcome, and 3) the disregard for the level of control inherent in the musculo-skeletal system (Davids, Button, & Bennett, 2003). The following section reviews the ecological perspective of motor behavior with a primary focus on Dynamical Systems Theory and Newell’s theoretical model of interacting constraints.

**Dynamical systems theory.** Dynamical systems theory (DST) rejects the concept of a symbolic representation guiding motor control and focuses on the natural control within the nonlinear dynamics of the musculo-skeletal system (Kelso, 1995;
Newell, 1986). DST incorporates biology, psychology, mathematics, and chemistry to describe biological movement systems as complex dynamical systems (Williams, Davids, & Williams, 1999). The human neuromuscular system is perceived as an integrated network of co-dependent subsystems composed of many interacting parts. These subsystems function over multiple scales of space and time. Rather than viewing the organism and environment as independent, DST views the organism-environment as the unit of analysis for studying movement in the natural environment. Ultimately, patterns of coordination and control emerge through physical processes of self organization and the constraints imposed on the neuromusculoskeletal system by the vast arrays of energy surrounding the biological organism. Over the past several decades, ecological-oriented scientists have effectively applied DST to movement coordination and control (Beek & O., 1988; Davids, Button et al., 2003; Kelso, 1995).

Support for DST has been primarily based on studies of two-limb interactions. Research shows that two stable coordination patterns naturally emerge during the timing of continuous, oscillatory, and bimanual movements (Oscillation tasks: Kelso, 1984; wrist rotation task: Lee, Blandin, & Proteau, 1996). The most stable pattern of coordination, termed in-phase, occurs when timing of landmarks within one cycle is similar (0 degrees). The less stable, anti-phase mode of coordination is a 180 degree shift from in-phase. A phase transition occurs when one coordination pattern changes to another. Increased speed of the anti-phase pattern results in an unintended phase transition to the in-phase mode of coordination. Importantly, this unintended phase transition illustrates the self-organization principle of DST, which asserts that organisms exhibit a natural tendency to perform more stable patterns and switch into more efficient
patterns under certain parameter conditions (e.g., increased speed). Additionally, these phase transitions to more stable patterns occur often without conscious control and can be accelerated or delayed with mental effort, as well as by emotional input (i.e., anxiety; Court, Bennet, Davids, & Williams, 1998). More specifically, self-organization is the principle of spontaneous pattern formation in movement that results from a large number of interacting components. Critically, self-organization alleviates much of the decision-making responsibilities about movement from the executive system, and therefore allows the biological system to operate automatically, yet subject to conscious intervention. DST proposes that scientists will gain a greater understanding of human motor behavior in organizational principles rather than psychological constructs such as symbolic representations in the CNS (Kelso & Schoner, 1988).

According to DST, different organizational states surface due to the internal and external constraints placed on a biological system (Newell, 1986). By limiting the number of possible configurations that a complex system can assume, these constraints impose the boundaries in which the human neuromuscular system must function and thus, channel and guide patterns of movement coordination and control. The biological system, at any time, will always produce optimal states of organization for the specific constraints acting on the system. Newell (1986) classified constraints into three categories, discussed next.

**Newell's theoretical model of interacting constraints (1986).** One of the most important contributions of Newell's model was the concept of “self-organizing optimality”, referring to the process in which unique interactions of constraints act on the individual neuromuscular system to produce optimal patterns of coordination and
movement. Newell also proposed that the constraints imposed on the dynamical movement system fluctuate over time, with the optimal pattern of movement coordination and control changing accordingly. According to Newell (1986), three categories of constraints converge to shape the patterns of coordination and control produced by the neuromusculoskeletal system. These constraints include organismic, environmental, and task (See Figure 2-5).

Organismic constraints are endogenous to the individual neuromusculoskeletal system and can be further divided into structural and functional constraints. Structural constraints are the physical constraints that are generally constant over time and include characteristics such as height, body mass, genetic make-up, and anthropometric and inertial characteristics of torso and limbs. Functional constraints vary over time, exhibit relatively faster rates of change, and can be physical or psychological. These constraints may include intentions, perception, emotion, memory, and decision-making. The current study will examine how different emotional states constrain the specific movement of gait initiation.

Environmental constraints are exogenous to the individual neuromusculoskeletal system and relate to the spatial and temporal layout of the surrounding world. These constraints include ambient light, temperature, altitude, and acoustic information. Newell and Jordan (Newell & Jordan, 2007) recently expanded the definition of the environmental constraints to include any physical constraint beyond the boundaries of the individual, such as tools and apparatus (i.e., originally considered task constraints).

Task constraints are specific to the task being performed by the individual and pertain to the goals and rules guiding performance and the boundaries and instructions
imposed on the performers. These constraints act as an umbrella over all the other constraints in determining what patterns of movement coordination the individual produces.

DST’s constraint led approach has important implications for scientists and clinicians. The traditional medical model considers variation in movement patterns as deviations from accepted norms and abnormal health as problems (Davids, Glazier, Araujo, & Bartlett, 2003). Alternatively, and taking a more adaptive approach, DST views disease as well as physical, cognitive, and perceptual disability as a constraint on the structure or function of the neuromusculoskeletal system. Furthermore, DST considers movement variability as a functional means of allowing the individual to adapt to these numerous and ever-changing constraints. Based on this approach, movement rehabilitation should focus on the achievement of an ideal motor pattern during therapy and aim to help the individual satisfy the unique constraints imposed on him/her, improving functionality and performance (Glazier & Davids, 2009). Empirically, efforts should seek to determine the interacting constraints most influential in shaping and guiding patterns of motor control and coordination. An increasing number of studies have used a constraint-led approach to the study of movement, whereby different environment and task constraints have been experimentally manipulated to examine their influence on different movements in individuals with and without movement disorders (Davids, Kingsbury, & George, 1999; Van Emmerik & Van Wegen, 2000). The goal of the current study is to explore which emotional states lead to the ideal performance on a gait initiation task in individuals with and without Parkinson disease.
Such knowledge could be used to optimize movement rehabilitation for those suffering from gait impairment.

While DST has provided both concepts and tools that have been successfully applied to the study of human movement, the theory is not without limitations. First, DST has been criticized for poorly defining important theoretical concepts, such as self-organization and constraints. For example, Beek et al. (1995) commented that some scientists incorrectly view self-organization as a magical ability which causes movements to emerge “out of the blue”. Secondly, few predictions of DST have been tested beyond the behavioral level, leading to a subsequent disconnect between the concepts of pattern formation and the neurophysiology of movement (Davids, Button et al., 2003).

**Summary**

Two significant perspectives of motor control currently exist. Cognitive-based theories are based on the idea that information about movements is symbolically represented and stored as abstract representation in the CNS. An alternative ecological approach views motor behavior as emerging from physical processes of self organization and the constraints imposed on the neuromusculoskeletal system. The cognitive and ecological perspectives have exerted a widespread impact on the field of motor learning and control, providing the basis for a flurry of experimental work. However, both theories are limited by their abstractness in major theoretical concepts (e.g., GMP, self-organization) and lack of reference to the mechanisms and structures of the human nervous system. A recently developed cognitively-based structural model of human action production (Glover, 2004) proposed the existence of separate neural structures underlying motor planning and motor control processes. The planning-control
model, while providing a nice conceptual and basic framework for understanding the production of movement, was empirically founded on studies of hand and arm movements (i.e., reaching and grasping movements) and therefore best applied to such movements. In sum, one model has yet to describe all the major features of human motor behavior, yet theoretical advancements continue through disproof of existing conceptual notions.

As previously described, postural instability and gait difficulties are cardinal symptoms of Parkinson disease. Moreover, current pharmacological and surgical therapies are limited in their ability to treat gait dysfunction, and in particular the initiation of gait. Therefore, my objective is to substantiate the potential of a largely untapped strategy to optimize the quality of gait initiation parameters through manipulation of emotion. Focus now shifts from discussion of motor theories to the specific movement of interest; gait initiation. Our theoretical approach to understanding the production of gait is influenced by concepts from the planning-control model and Newell’s constraint based approach. As is discussed further, the initiation of gait involves a preparatory phase (postural adjustments prior to first step) and a locomotive phase (execution of first and second step), each of which is regulated by slightly different neural processes. As proposed in Glover’s model, planning processes likely regulate the initiation of the preparatory postural adjustments. Additionally, the automatic aspects of gait (i.e., rhythmic limb movements during gait) are likely controlled by processes, which that operate outside of conscious awareness. However, as the transition is made from the preparatory phase to the locomotive phase of gait initiation to the automatic phase of gait, distinguishing between motor planning and
motor control processes becomes difficult. As such, gait initiation will be viewed as emerging from the interaction of a preparatory phase and an execution or locomotive phase, rather than strictly planning and control processes.

We will also broadly adopt Newell’s constraint led approach to understanding how gait initiation is restricted by task, environmental, and organismic constraints. Humans adapt their gait in response to numerous situational constraints, and in the context of this review, the emotional state of the individual is the primary situational constraint of interest. Additionally and as will be discussed later, emotional state interacts with task constraints (e.g., the goal of the movement such as to approach or avoid an object) to determine the impact of emotion on movement. Organismic constraints include unique characteristics of the individual, including disability. As such, Parkinson disease is considered a physical constraint on the function of the neuromuscular system. Another organismic constraint of interest is an individual’s dispositional susceptibility to emotional reactivity which is particularly important when studying PD, a disease characterized by high rates of apathy, depression, and anxiety disorders. Before exploring the potential impact of the aforementioned constraints on gait initiation, it is critical to achieve an understanding of the processes and neural substrates regulating this specific movement, which is discussed below.

**Gait Initiation**

Gait, or bipedal locomotion, is a functional task involving the complex interaction and coordination of the major lower extremity joints of the body. This fundamental task is critical to performing many activities of daily living. Consequently, scientists have sought to understand the typical body movements involved in normal gait, pathological conditions of gait, as well as therapeutic interventions to improve gait dysfunction. The
follow discussion centers specifically on the initiation of gait, providing a description of 'normal' gait initiation, the neural mechanisms underlying gait initiation, and gait initiation dysfunction in PD.

Gait initiation (GI) is the phase between motionless standing and rhythmic walking (Hallet, 1990). Successful GI requires effective balance control as one moves from stable balance to continuously unstable gait (Halliday, Gai, Blessing, & Geffen, 1990). Prior to the initiation of the stepping movement, anticipatory postural adjustments (APAs) decouple the center of mass (COM) and the net center of pressure (COP). These postural adjustments include a series of muscle activations and changes in ground reaction forces that move the net center of pressure (COP) backward and toward the initial swing limb to move the COM forward over the stance limb (Crenna, Frigo, Giovannini, & Piccolo, 1990; Massion, 1992). Execution of the first step begins when weight has been transferred to the stance limb (Crenna et al., 1990).

Recent investigations of gait initiation indicate that the COP trajectory during the preparatory postural adjustments can be divided into three separate periods (S1, S2, S3) based on two important landmark events (See Figure 2-6: Halliday, Winter, Frank, Patla, & Prince, 1998; Hass et al., 2004; Martin et al., 2002). S1 begins with the signal to initiate gait and ends when the COP is located at the first landmark, the COP’s most posterior and lateral position toward the initial swing limb. This backward displacement, caused by deactivation of the gastrocnemii and soleus muscles (Winter, 1995), produces the momentum needed to initiate forward gait (Polcyn, Lipsitz, Kerrigan, & Collins, 1998). Another important aspect of the S1 phase is the generation of stance side momentum caused by the lateral shift toward the swing limb to propel the COM
towards the stance limb (Polcyn et al., 1998). A momentary loading of the swing leg by
the hip abductors produces this lateral displacement (Winter, 1995). S2 is the actual
transfer of the COP from landmark 1 towards the stance limb, ending at the position
under the stance limb on which the COP begins to move forward under the foot
(landmark 2). This rapid transfer of the COP toward the stance limb propels the COM
forward accelerating it away from the stance limb (Jian, Winter, Ishac, & Gilchrist,
1993). The final region of the COP trajectory, S3, begins at landmark 2 and ends at toe
off of the initial stance limb as the COP moves anteriorly.

The neural control of gait initiation and execution

As addressed earlier, the basal ganglia consist of the gray matter located at the
base of the cerebral hemispheres, consisting of a group of interconnected subcortical
nuclei including the striatum (caudate and putamen), globus pallidus, subthalamic
nucleus (STN), and the substantia nigra (SN). Disorders of the basal ganglia, such as
Parkinson Disease, are often characterized by an inability to initiate voluntary
movements, slowness of movement, and an abnormal postural tone. Disturbances in
gait initiation and postural instability are particularly prominent in patients with PD. The
presence of gait difficulties in disorders of the basal ganglia combined with research
implicating the basal ganglia in the planning and execution of voluntary movements
(Alexander & Crutcher, 1990; DeLong, 1990; Middleton & Strick, 2000) led researchers
to propose that the basal ganglia play a prominent role in controlling locomotion.
Although knowledge is still limited, research on primates and rats suggests that gait is
continuously regulated by inhibitory projections from the basal ganglia. Takakusaki et al.
(Takakusaki, Habaguchi, Ohtinata-Sugimoto, Saitoh, & Sakamoto, 2003) postulated that
multiple channels from the basal ganglia - brainstem system and the basal ganglia-
thalamocortical system control postural muscle tone and regulate the central pattern
generators (CPG) in the spinal cord. The CPGs are circuits in the spinal cord
responsible for producing the basic locomotor rhythm and alternating muscle activity
during locomotion (Ivanenko, Poppele, & Lacquaniti, 2009). While details of this circuitry
in humans are primarily unknown, Cazaletes & Bertrand (2000) suggest that upper
lumbar segments in the spinal cord are the major site for CPG activity. Central
commands combined with proprioceptive feedback control CPGs (Drew, Prentice, &
Schepens, 2004). As demonstrated in Figure 2-7, GABAergic basal ganglia output to
the motor cortices via the thalamus is thought to regulate the volitional aspects of gait,
while GABAergic output to the brainstem regulates the automatic control processes of
locomotion. The role of these two systems in controlling gait is outlined next.

**Basal ganglia-thalamocortical loop.** The basal ganglia are involved in up to
five known parallel and segregated circuits linking the cerebral cortex, basal ganglia,
and thalamus (Alexander, DeLong, & Strick, 1986). The basal ganglia thalamocortical
loops with the motor cortices are thought to control the volitional aspects of locomotion,
such as initiation and termination of gait and modulation of gait patterns based on
environmental cues. GABAergic neurons from the internal segment of the globus
pallidus (GPI) influence cortical areas via the thalamic relay neurons. This basal ganglia
output reaches both the premotor cortices and primary motor cortex, each of which
serves a different function in the control of gait (See Figure 2-8).

The secondary motor areas likely control the postural adjustments preceding gait
initiation (Massion, 1992). Research on bipedal walking in monkeys has shown that the
supplementary motor area (SMA) has dense connections with the pontomedullary
reticular formation (PMRF: Keizer & Kuypers, 1989), the brain area responsible for regulating postural control during walking. Furthermore, research on quadrupeds indicates that the PMRF is involved in the control of posture via brainstem – spinal pathways that are activated by motor corticofugal projections (Drew, Prentice, & Schepens, 2004; Kably & Drew, 1998; Prentice & Drew, 2001; Schepens & Drew, 2003). As such, the cortico-reticular projections from the SMA are assumed to control the timing and planning of the anticipatory postural adjustments that precede gait initiation. This notion is supported by multiple studies showing the activation of the SMA during gait initiation. For example, Yazawa et al. (1997) found greater bilateral activation of the SMA during initiation of externally cued gait relative to simple foot dorsiflexion, suggesting that the SMA plays a more important role in gait initiation than in simple foot movements. Additionally, several studies have shown activation of the SMA, lateral premotor areas (PM), and the cingulated motor areas (CMA) during gait related activity (Fukuyama et al., 1997; Hanakawa et al., 1999; Miyai et al., 2001). Finally, individuals with damaged premotor cortices, including the SMA, frequently display freezing of gait or gait initiation difficulties.

While the preparatory phase of gait initiation is likely controlled by the SMA, the primary motor cortex controls the stepping phase of gait initiation (Massion, 1992). Research indicates that basal ganglia output to the motor cortex controls the generation and velocity of voluntary movement (DeLong et al., 1984; Turner & Anderson, 1997). The primary motor cortex projects directly to the spinal cord, allowing for direct influence on the CPGs. Additionally, research on macaque monkeys and cats has provided evidence that the primary motor cortex has excitatory glutamatergic projections to the
structures in the brain stem regulating postural muscle tone (i.e., PPN: Matsumura et al., 2000) and locomotion (i.e., PMRF: Matsuyama & Drew, 1997). Studies on cats indicate that the fine control of stepping movements, as well as adaptive walking movements, are largely dependent on the primary motor cortex (Armstrong, 1988; Drew, Jiang, Kably, & Lavoie, 1996). Less is known about the cerebral control of human gait. However, using a near-infrared spectroscopic topography technique, Miyai et al. (2001) found increased levels of oxygenated and total hemoglobin in the primary motor cortex and SMA when participants walked on a treadmill. Activation of the primary and secondary motor cortices during the volitional control of walking in healthy human subjects has also been demonstrated in studies using fMRI with mental imagery paradigms (Jahn et al., 2008) and in studies applying single photon emission computed tomography (SPECT: Fukuyama et al., 1997; Hanakawa et al., 1999).

**Basal ganglia – Brain stem system.** The basal ganglia – brain stem system controls the automatic regulation of postural muscle tone and rhythmic limb movements during gait through medial and lateral projections to the mesopontine tegmentum of the brain stem (See Figure 2-9). In the mesopontine tegmentum, the midbrain locomotor region (MLR) and the muscle tone inhibitory region in the ventrolateral part of the pedunculopontine nucleus (PPN) are the two areas important for control of locomotion and postural muscle tone, respectively (Takakusaki, Habaguchi et al., 2003). Research on decerebrate cats with the striatum, thalamus, and cerebral cortex removed but SNr intact indicates that GABAergic efferents 1) to the PPN suppresses activity of the muscle tone inhibitory system and 2) to the MLR suppresses activity of a locomotor executing system (Takakusaki, Habaguchi et al., 2003). Specifically, GABAergic
efferents from the SNr activate cholinergic neurons in the PPN (Grofova & Zhou, 1998; Saitoh, Hattori, Song, Isa, & Takakusaki, 2003), which in turn activate the muscle tone inhibitory system via choloinoceptive pontine reticular formation (PRF) neurons. The inhibitory system controls the level of muscle tone by regulating the excitability of the motor neurons of the extensor and flexor muscles via postsynaptic inhibitory effects on α and γ motor neurons (Takakusaki, Kohyama, & Matsuyama, 2003; Takakusaki, Kohyama, Matsuyama, & Mori, 2001). Additionally and as shown in Figure 9, the basal ganglia efferent to the MLR controls the locomotor pattern through two major pathways (i.e., pontomedullary locomotor strip, PMLS; medial medullary reticulospinal tract) descending from the MLR to the spinal cord (Grillner, 1981; Takakusaki, Habaguchi et al., 2003). These two pathways activate the CPG’s in the spinal cord, controlling rhythmic limb movements.

Several studies indicate that the basal ganglia-brainstem system plays an important role in the initiation of gait (Garcia-Rill, 1991; Skinner, Kinjo, Henderson, & Garcia-Rill, 1990). Takakusaki et al. (2003) found that stimulating the SNr in rats with progressively increasing strength disturbed rhythmic limb movements, increased cycle time, and delayed onset of gait. Thus, Takakusaki suggested that the SNr GABAergic projections to the brainstem are involved in both the steady (e.g., postural control, rhythmic limb movements) and dynamic aspects (e.g., gait initiation) of gait. Several studies have also demonstrated that lesioning the PPN in primates produces akinetic symptoms (Aziz, Davies, Stein, & France, 1998; Kojima et al., 1997). Furthermore, research on individuals with Parkinson Disease has revealed that damage to the PPN or pathological input to the PPN from the basal ganglia causes movement initiation
problems (Nandi, Jenkinson, Stein, & Aziz, 2008). The cholinergic PPN neurons likely regulate the initiation of gait through the modulation of postural muscle tone (Takakusaki, Habaguchi et al., 2003). Takakusaki et al. (2004) suggested that when an individual is preparing to initiate gait, tonic activity of the SNr neurons would continuously inhibit the PPN and MLR until the arrival of a signal triggering gait onset. Upon the arrival of a trigger, decreased inhibitory input from the SNr to the brainstem structures would release the activity of the locomotor system (MLR → CPGs) and the muscle tone control system (PPN → muscle tone inhibitory system) leading to the initiation of locomotion accompanied by the reduction of the level of muscle tone. Importantly, the PPN and pontomedullary reticular formation receive excitatory input from the motor cortices and direct inhibitory input from the basal ganglia. Thus, the control of postural muscle tone and locomotion is likely regulated in parallel by a combination of basal ganglia inhibition and motor cortex excitation of the brainstem.

**Gait initiation deficits in Parkinson disease**

A typical sign of akinesia (i.e., failure or slowness of willed movement) in persons with PD is difficulty initiating gait (Hallet, 1990). These gait initiation difficulties emerge when PD patients begin to suffer from postural instability and progressively appear at the later stages of the disease. Additionally, gait initiation dysfunction is considered one of the most debilitating motor symptoms of PD and often remains even after the relief of all other symptoms. A major pathophysiologial mechanism underlying hindered gait initiation in PD patients is start hesitation (Burleigh-Jacobs, Horak, Nutt, & Obeso, 1997; Crenna et al., 1990) and inefficient anticipatory postural adjustments (Burleigh-Jacobs et al., 1997; Crenna et al., 1990; Gantchev, Viallet, Aurenty, & Massion, 1996; Halliday et al., 1998; Hass, Waddell, Fleming, Juncos, & Gregor, 2005; Rosin, Topka, &
Dichgans, 1997). Crenna et al (1990) showed that PD patients exhibit an increased duration of the postural phase of gait initiation, decreased propulsive forces during both the postural phase and the stepping phase, and reduced length and velocity of the first two steps. Similarly, Halliday and colleagues (1998) demonstrated that while gait initiation in PD is characterized by similar temporal and spatial patterns to that of healthy older and younger individuals, the AP and ML displacements during the APA’s are smaller and the step lengths and velocities during the stepping phase are shorter and slower, respectively (See Figure 2-10). Several studies have since supported Crenna and Halliday’s results (Rocchi et al., 2006; Vaugoyeau, Viallet, Mesure, & Massion, 2003), confirming that gait initiation parameters in individuals with PD are slower, smaller, and less forceful. As the disease progresses, these gait abnormalities become more pronounced, limiting the quality of life.

The motor deficits of PD are caused by progressive degeneration of the dopaminergic neurons of the substantia nigra pars compacta and the subsequent DA depletion of the striatum (Forno, 1996). As mentioned earlier, striatal DA depletion is estimated to have reached 70% at the time of diagnosis of PD, and even up to 90% in the posterior putamen (the region of the striatum that is part of motor circuit) (Whone, Moore, Piccini, & Brooks, 2003). Ultimately, the dopaminergic denervation of the striatum increases the activity of the basal ganglia output nuclei resulting in increased inhibitory control over the basal ganglia-thalamocortical loop and the basal ganglia-brainstem system (Blandini et al., 2000; Takakusaki, Tomita, & Yano, 2008). Gait dysfunction is likely a specific disturbance of the GABAergic basal ganglia output to both the motor cortices and the brainstem (See Figure 2-11).
In the basal ganglia-thalamocortical loop, the motor cortical areas receiving basal ganglia output use the corticospinal tract to control the volitional aspects of locomotion, including the initiation of gait. In PD, a loss of dopaminergic neurons of the SNc and the subsequent abnormalities in the basal ganglia thalamocortical circuit leads to defective activation of the motor related cortical areas during gait initiation (DeLong, 1990; Playford et al., 1992). Specifically, the dopaminergic denervation of the striatum leads to decreased inhibitory control over the GPI and SNr, which causes excessive inhibition of the thalamocortical projections to the motor related areas. Such thalamocortical projections fail to facilitate activation of the motor cortical areas controlling gait initiation (i.e., SMA and primary motor cortex). Impaired anticipatory postural adjustments required for successful gait initiation may reflect reduced activity of the SMA. Additionally, decreased cortical excitation to the PPN could increase the level of muscle tone, while decreased cortical excitation to the reticular formation and spinal cord may decrease the amount (hypokinesia) and velocity (bradykinesia) of movement (Takakusaki et al., 2008).

In the basal ganglia-brainstem system, the basal ganglia output to the MLR controls the automatic aspects of locomotion while output to the PPN regulates muscle tone. In PD, excessive GABAergic output from the SNr to the PPN, in combination with decreased cortical excitation of the PPN, may increase the level of muscle tone (Takakusaki, Habaguchi et al., 2003; Takakusaki et al., 2004). Additionally, several neuropathological studies on humans have shown that individuals with PD have up to a 50% loss of the cholinergic neurons of the lateral part of the PPN (Gai, Halliday, Blumbergs, Geffen, & Blessing, 1991; Hirsch, Graybiel, Duyckaerts, & Javoy-Agid,
Thus, the suppression of PPN activity as well as the loss of PPN neurons could result in gait and posture abnormalities in PD. Furthermore, excessive GABAergic inhibition of the MLR combined with decreased cortical excitation of the MLR likely contributes to gait failure (Takakusaki, Habaguchi et al., 2003; Takakusaki et al., 2004). Dysfunction of the basal ganglia-brainstem system along with that of the basal ganglia-thalamocortical loop therefore, appears to be the most likely underlying locus for the pathogenesis of gait difficulties in Parkinson Disease (Takakusaki et al., 2008).

**Summary**

In sum, gait initiation is likely regulated in parallel by the basal ganglia thalamocortical system and the basal ganglia-brainstem system. Individuals with Parkinson disease exhibit disturbance in both systems caused by a loss of dopaminergic neurons of the SNc and a loss of PPN neurons. This dysfunction likely causes the slower, smaller and less forceful gait initiation parameters characteristic of PD. Identification of the constraints that impact gait is essential to the optimization of gait parameters in individuals with Parkinson disease. Despite the growing body of literature supporting the long held notion that emotions prepare the body for action, little research has investigated how this situational constraint influences the initiation of gait.

Before discussing the current evidence for emotion’s impact on movement, a general overview of emotion is provided. Knowledge of emotion theory, the circuitry of emotion, as well as the emotional deficits that typically characterize PD is essential to understanding 1) how emotion and motor systems are integrated in the human brain and 2) how PD may impact emotion’s influence on movement.
Overview of Emotion

The purpose of this section is to describe the prominent theoretical perspectives in the study of emotion, as well as the neural mechanisms involved in emotional processes. The section will conclude with a review of emotional dysfunction in Parkinson disease.

Theories of Emotion

Beginning with Darwin in the late 1800s, behavioral, biological and cognitive views of emotion have developed and progressed almost independently. However, most theorists would now agree that emotion consists of several components including the subjective experience of affect, expressive behaviors, an integrated neurobiological response, and cognitive perception (Barlow, 2002). A brief overview of the behavioral, cognitive, and biological approaches to emotion is provided, followed by a widely accepted integrative model of emotion that provides a foundation for understanding and analyzing the influence of affective states on human movement.

Behavioral theories of emotion

In 1872, Charles Darwin published *The Expression of Emotions in Man and Animals* and initiated the study of emotional behavior. Darwin investigated expressive behavior, emphasizing facial expressions and posture as fundamental aspects of emotion. He argued that the behavioral expressions of emotion are innate and have evolved because of functional significance; the preparation for action and communication. Importantly, his expressive-behavioral approach assumes that the basic patterns of emotion are fundamentally different. Studies by Ekman in the 1970s (Ekman & Friesen, 1971) supported Darwin’s ideas by demonstrating the existence of distinct patterns of facial expression for primary emotions, such as fear, anger,
happiness, and disgust across numerous and varied cultures. Additional behavioral and psychopathological evidence also supported this notion (Ekman, Levenson, & Friesen, 1983; Izard, 1990).

In *The Principles of Psychology* (1890) and *Emotions* (1922, written with physiologist C. Carl Lang), William James proposed a highly influential approach to emotions. The James-Lang Theory proposed that certain behavioral and bodily reactions (e.g., changes in heart rate and blood pressure) are associated with specific emotions, and humans feel emotions because they perceive these bodily and behavioral changes. James proposed that three steps are necessary to produce an emotion. First, particular visceral, vascular or somatic changes are initiated in response to some antecedent event. Secondly, peripheral sensory receptors, detecting these changes, transmit signals to the brain. Finally, the brain produces activity necessary for feeling an emotion. Consistent with Darwin’s theory, the James-Lang theory views basic emotions as differing from one another and having adaptive functional value. However, visceral reactions, rather than facial expressions, were viewed as the primary component of emotion. Research eventually refuted James ideas by showing that emotions can be experienced without visceral or somatic changes (Cannon, 1929; Lang, 1994).

**Cognitive theories of emotion**

Several cognitive approaches to emotion have been proposed. Schachter & Singer (1962) first asserted that when humans experience generalized arousal, arousal is labeled based on the appraisal of the context. For example, if an individual were aroused by the presence of an intruder in the home, then arousal would be labeled as fear. However, if an individual experienced the same level of arousal during sexual
relations, then arousal would be labeled as love. Thus, emotion results from perception of a generalized arousal state, which is based on appraisal of the environmental context. Schachter and Singer's theory of emotion, termed Appraisal Theory, was empirically tested in the following decades and received little support (Marshall & Zimbardo, 1979; Reisenzein, 1983). Several studies showed that emotional behavior can occur in the absence of arousal (Lang, 1968).

The second cognitive approach, also based on cognitive appraisal, was proposed by Richard Lazarus in the early 1970’s (Lazarus, 1991; Lazarus, Averill, & Opton, 1970). Lazarus asserted that cognitive appraisals are the primary determinants of the emotional response. For example, if an individual appraises an approaching dog as dangerous, then he/she will experience fear. Supporting Lazarus’s theory, Speisman et al. (1964) showed that the stress response (i.e., skin conductance response) of subjects watching an anxiety-provoking film was greater when the film was accompanied by a soundtrack which heightened the threatening aspects of the film compared to an intellectualization soundtrack and no soundtrack. Thus, subjects’ cognitive appraisal of the traumatic events in the film played an important role in determining their emotional responses. However, several problems have emerged with Lazarus’s theory. First, humans often experience irrational emotions, in which the emotional response is not preceded by any conscious rational appraisal (Barlow, 2002). Secondly, Zajonc (1984) showed that neural activity associated with affective processes can occur faster than the neural activity required for cognitive processes. According to Zajonc, emotions can be generated without prior cognitive processes, such as appraisals.
Recently, psychologists have developed a more complete model of processing emotional information based on theories of embodied cognition (Niedenthal, 2007; Niedenthal, Mondillon, Winkielman, & Vermeulen, 2009). These theories view knowledge as “embodied” or grounded in bodily states and processes in modality specific systems that occurred when the information was initially acquired (Niedenthal, Barsalou, Winkielman, Krauth-Gruber, & Ric, 2005; Smith & Semin, 2007). Interaction with a particular entity or situation during the initial acquisition of information (i.e., encoding) engages the sensory, motor, and introspective systems. Future activation of any one of these response modalities, when the original entity or situation is not present, results in partial reactivation of the other encoding modalities. As applied to emotion, emotional information processing involves reactivating at least potions of neural states across the relevant modalities that occurred during the original encoding of that emotion. Niedenthal (2007) gave a schematic illustration of embodied emotion using the perception of an emotional stimulus: a snarling bear (See Figure 2-12). Encountering a snarling bear is a multimodal experience involving seeing the bear, hearing the bear growl, feeling afraid, and withdrawing or running away from the bear. Thus, neurons in the visual, auditory, affective, and motor systems are activated and highly interconnected during this encounter. When thinking about or seeing a picture of a snarling bear in the future, the visual impression of the bear reactivates the visual system’s neurons followed by a cascade of neuronal activation patterns similar to the original experience, with a selective focus on aspects of the experience most salient to the individual. As the emotion of fear is likely to be a particularly salient aspect of the experience, this affective state is likely to be reinstated followed by reactivation of
parts of the motor system (e.g., withdrawal/avoidance behavior). Further discussion of
the embodied emotion view as it explains the relationship between emotion and
approach/avoidant movements is presented in the Emotion and Movement section.

**Biological theories of emotion**

Walter Cannon (1929) first proposed that emotions are a function of brain
processes. Cannon's research showed that the surgical removal of various brain
regions in animals influenced the experience of emotions. For example, emotions
appeared to be released when the cerebral cortex was removed. Therefore, Cannon
hypothesized that the cerebral cortex exerted control over emotions, rather than having
direct involvement in the generation of emotions. Researchers continued to investigate
the brain processes underlying emotion using methods of brain ablation and stimulation
to determine specific anatomical regions associated with different emotions (Barlow,
2002). The limbic system was the focus of much of the early investigations (e.g.,
MacLean, 1963). To date, researchers have discovered multiple cortical and subcortical
pathways underlying emotional processes (LeDoux, 1996; Lang, Bradley, & Cuthbert,
1998) and recently, scientists have begun to focus on the relationship of emotions to
specific neurotransmitters and neuromodulator systems. Several neuroscientific models
of emotion are presented in the Circuitry of Emotion section later.

**Integrative theories of emotion**

Modern affective theorists now apply a more integrative study to emotion, and
realize emotional processing involves a complex interaction of neurobiological,
behavioral, and cognitive systems. One the most prominent integrative theories of
emotion, Peter Lang's biphasic theory (Lang, 1995; Lang, Bradley, & Cuthbert, 1998),
conceptualizes emotions as fundamental action dispositions which have evolved to
activate behaviors essential for survival. Products of Darwinian evolution, emotions are organized by two motivational systems in the brain that adaptively respond to appetitive and aversive stimuli (Dickinson & Dearing, 1979; Konorski, 1967; Lang et al., 1998). The appetitive system, associated with pleasant emotions, directs behavioral responses to approach appetitive stimuli. The aversive system, associated with unpleasant emotions, directs behavioral responses to withdrawal from aversive stimuli. Based primarily on animal research, Lang hypothesized that each system consists of distinct neurophysiological circuits in the brain, which are primarily subcortical. Furthermore, each system can vary in intensity of activation (metabolic or neural). Thus, according to Lang, all human emotions can be organized according to two dimensions: valence (pleasant v. unpleasant) and arousal (intensity of activation). Furthermore, a large database has shown that emotional expression can be measured in three reactive response systems including 1) evaluative and expressive language, 2) physiological events, and 2) behaviors. Before discussing the neurocircuitry of emotion, a brief overview of the defensive and appetitive motivational systems, as indexed by the physiological and behavior systems, is provided.

**Defensive system.** Animal studies show that threatening cues activate the defensive system, preparing the organism for overt defensive behavior including freezing and active flight (Fanselow, 1994), fear bradycardia (Kapp, 1979), and potentiation of the startle response (Davis, 2000). Several animal behavioral theorists propose that defensive reflex reactivity to threatening stimuli is sequentially organized to reflect the imminence of threat (e.g. Blanchard & Blanchard, 1977; Fanselow, 1994). Accordingly, passive responses (e.g., freezing) initially increase with the proximity of a
threatening stimulus, however as the predator reaches striking distance the organism shifts to overt defensive behavior (e.g., fight or flight). Based on physiological reactions measured during affective picture perception, Lang and colleagues (Codispoti, Bradley, & Lang, 2001; Lang, Bradley, & Cuthbert, 1997) proposed a similar defensive response in humans, which they termed the defensive cascade model. According to the model, increases in defensive motivation correspond to patterns of change in specific response systems (See Figure 2-13). Importantly, the level of arousal indicates the level of defensive activation. In the early stages of defense, characterized by low activation, orienting and attention to the threatening stimulus is heightened. In this stage physiological changes include cardiac deceleration, inhibition of the probe startle reflex, and moderate increases in electrodermal activity. As arousal increases and threat becomes more imminent, metabolic mobilization for active defense replaces orienting behavior, signaled by increased electrodermal activity and potentiated startle reflex (Bradley, Cuthbert, & Lang, 1999). Additionally, at higher levels of defensive activation when the organism is preparing for action, the cardiac response shifts from deceleration to acceleration. Finally, these physiological changes support the selected overt defensive reactions (e.g. fight or flight) when danger is most proximal. Lang et al. (1997) suggested that in picture-viewing contexts, unpleasant pictures most often elicit reactions analogous to the freezing animal and the post-encounter stage. Furthermore, pictures of attack and mutilation, representing more imminent threat than most other unpleasant picture categories (e.g., pollution, loss, illness, and contamination), likely activate the defensive system most strongly.
**Appetitive system.** The appetitive system is activated in contexts that promote survival (i.e., procreation, nurturance, ingestion) and organizes behavior involved in approaching desired rewards or goals. Similar to defensive motivation, increased activation involves an initial orienting followed by overt action. This orienting period is characterized by an initial cardiac deceleration and increased electrodermal activity. Furthermore, engagement of the appetitive system is associated with startle reflex inhibition (Bradley et al., 1999), possibly reflecting an increased inhibition of defensive reflexes during appetitive activation or sustained motivated attention (Bradley, Cuthbert, & Lang, 1993). Stimuli eliciting greater activation of the appetitive system (erotic couples v. happy families) produce greater changes in the different response systems. The current study will examine whether such affective pictures activate the defensive and appetitive systems similarly in individuals with PD compared to healthy controls, as evidenced in the fundamental parameters involved in movement execution.

In summary, the past century has seen the development of several independent views of emotion which have uniquely contributed to our understanding of the experience of emotion. Today, affective theorists generally accept the idea that emotional experience involves the integration of each of these fundamental components. In addition to the aforementioned theories of emotion, several purely structural models of emotion have been proposed. The following section reviews these models, as well as the specific neural structures and circuits underlying emotional processes.

**Circuitry of Emotion**

The focus of this section is threefold: 1) to describe the key neuroscientific models of emotion which have guided contemporary research, including single system
models of emotion, dual system models of emotion, and categorical accounts of emotion, 2) to elucidate the role of subcortical and cortical structures in the expression of emotions, and 3) to describe limbic circuits specifically involving the basal ganglia. These concepts are reviewed with an eye towards identification of common structures and circuits that integrate emotion and motor systems.

**Neuroscientific models of emotion**

Several models emanating from the neuroscience of human emotion have been developed based on fMRI and PET studies, as well as studies using lesion methods and pharmacological manipulations on animals and humans. MacLean (1949; MacLean, 1952) proposed one of the earliest and most popular models, suggesting that the broad array of emotions humans experience are regulated by a single neural system comprised of a special group of integrated brain structures, called the limbic system. The primate forebrain was thought to have evolved in hierarchical fashion into three basic patterns referred to as reptilian, paleomammalian, and neomammalian. The neocortical tissue, which is only well developed in mammals, was predicted to be involved in cognitive processes. However, the paleomammalian “old” cortex included primitive circuits that had been conserved throughout mammalian evolution. MacLean referred to this “old” cortex as the limbic system and the related subcortical ganglia, which he proposed mediated all emotional processes. The primary structure of the limbic system included the hippocampal formation, along with the hypothalamus, amygdala, septal area, and orbito-frontal cortex. While the limbic system later expanded to include areas of the midbrain (Nauta, 1979), the inclusion criteria for limbic brain regions remain largely undefined. MacLean’s model was widely accepted by affective scientists until it was challenged on both theoretical and anatomical grounds particularly
during the last two decades. PET and fMRI studies have shown that emotional processes likely involve a more widespread pattern of activity than proposed by the Limbic System model of emotion. Thus, MacLean’s Limbic System theory of emotion is regarded as an inadequate structural theory of emotion (LeDoux, 2000).

Another early neural model of emotion hypothesized that all emotions, regardless of valence, are preferentially processed in the right hemisphere (Sackeim & Gur, 1978). Support for this hypothesis has primarily been acquired through lesions studies and patients with right hemisphere damage (Bowers, Bauer, & Coslett, 1985; DeKosky, Heilman, Bowers, & Valenstein, 1980; Heller, 1993; Mandal, Mohanty, Pandey, & Mohanty, 1996). However, behavioral studies with neurologically intact humans have provided conflicting evidence for the right-hemisphere hypothesis. For example, Smith and Bulman-Fleming (2005) found a right-hemisphere advantage for processing negative stimuli, but failed to detect any hemispheric differences in processing positive stimuli. Additionally, the right-hemisphere model has been refuted by several neuroimaging studies showing the involvement of both the right and left hemispheres during the perception of emotion (Murphy, Nimmo-Smith, & Lawrence, 2003). Collectively, the extant research indicates that the right hemisphere likely plays a critical role in only certain aspects of emotional processing, such as the recognition of emotion, as expressed by speech prosody and facial expressions (Bowers et al., 1985; Bowers, Blonder, Feinberg, & Heilman, 1991; Davidson, Shackman, & Maxwell, 2004; Harciarek, Heilman, & Jodzio, 2006; Heilman, Blonder, Bowers, & Valenstein, 2003). The prosodic elements of speech include the melodic and rhythmic components of spoken language, such as tone of voice, which play a significant role in communicating the emotional state.
of an individual (e.g., happy, sad, angry). While this refinement to the right-hemisphere model has received considerable support, affective theorists have begun to conceptualize the neural basis of emotion based on dimensional and multisystem neuroscientific models.

Affective theorists have proposed two primary dimensional models of emotion. The valence asymmetry model (Davidson, 1984) hypothesizes that the left cortical areas are involved in the processing of positive emotions, while the right cortical areas are involved with processing of negative emotions. The action tendency model of emotion, representing a variation of the valence asymmetry model, organizes emotions based on approach and withdrawal action tendencies (Carver, Sutton, & Scheier, 2000; Davidson, 1998; Lang et al., 1997). This model predicts differential involvement of the left- and right- anterior brain regions in approach- and withdrawal-related emotions, respectively. For example, according to the action-tendency/ motivational direction model, the emotion of anger, although negative in valence, is considered an approach-related emotion and therefore should be preferentially processed by the left hemisphere (Harmon-Jones & Allen, 1998). EEG research and brain-based behavioral studies have provided greater support for the approach/ avoidance classification of emotions, compared to the valence classification (Carver & Harmon-Jones, 2009; Harmon-Jones & Allen, 1998; Lane, Reiman, Axelrod, Yun, Holmes, & Schwartz, 1997). A meta-analysis examining the functional neuroimaging data on the study of human emotion (106 PET and fMRI studies) found greater left compared to right sided activity for approach-related emotion, but symmetrical activity for withdrawal related emotions (Murphy et al., 2003). Several explanations have been proposed for why the asymmetry
model of approach/withdrawal emotion has only been partially supported. First, the classification of emotions based on their associated action-tendencies may only apply for particular emotions (e.g., anger, happiness). Additionally, confusion exists regarding the categorization of certain emotions, such as fear. Although fear is generally associated with a withdrawal response, it can also elicit approach to safe places or an approach-related “fight” response to threatening stimuli (Blanchard & Blanchard, 1994). Finally, Davidson suggested that resting brain asymmetries, called affective style, predict reactivity to experimental elicitors of emotion (Davidson, 1998). Specifically, individuals with greater right frontal activation demonstrate greater reactivity to unpleasant stimuli, while individuals with greater left frontal activation demonstrate increased reactivity to pleasant stimuli. Thus, individual differences in affective style could influence the degree of left and right brain activation in response to emotional stimuli and many neuroimaging studies have not accounted for such differences.

Categorical accounts of emotion are becoming increasingly popular, which propose that unique patterns of neural activity mediate a small set of discrete emotions (Ekman, 1999). In contrast to the dimensional models of emotion which link neural activity to specific hemispheres, the categorical account suggests regional specialization for the discrete emotions of fear, disgust, and anger (Murphy et al., 2003). In particular, research shows the amygdala to be selectively associated with fear (Laber, LeDoux, Spencer, & Phelps, 1995; Calder, Lawrence, & Young, 2001; Adolphs, Russell, & Tranel, 1994). However, many investigators now view the amygdala as a detector of salience, rather than specifically fear (this issue is revisited later in the review). The globus pallidus of the basal ganglia and the insula appear to be particular
active in mediating the emotion of disgust (Sprengelmeyer et al., 1997; Calder, Keane, Manes, Antoun, & Young, 2000; Gray, Young, Barker, Curtis, & Gibson, 1997), while anger has been linked with activity of the lateral orbital frontal cortex (OFC: Adolphs et al., 1999).

While both the action-tendency and categorical neuroscientific models of emotion have received considerable support, no available model can comprehensively account for the neurological basis of all emotions. The specific brain regions hypothesized to have specialized functions for emotional processing are outlined next.

The role of specific brain regions for emotional operations

The potential functional roles for several brain structures implicated in emotional operations are summarized next. In particular, this section will focus on the brain regions with the greatest implications for PD, considering their functions in emotion and movement integration. To begin, the roles of the medial prefrontal cortex (MPFC) and anterior cingulated cortex (ACC) are briefly addressed.

**Medial Prefrontal Cortex and ACC.** The medial prefrontal cortex is thought to be involved in emotional processing. Research has demonstrated that the MPFC is activated in response to emotional films, pictures, and recall, as well as positive and negative emotions (Lane et al., 1997; Reiman, Lane, Ahern, et al., 1997). Additional research suggests that the MPFC may be specifically involved in the cognitive aspects of emotional processing (Drevets & Raichle, 1998; Lane et al., 1998), such as attention to emotion and appraisal of emotion. The cognitive appraisal of aversive stimuli (versus passive viewing) and regulating emotion while viewing emotionally evocative stimuli have been associated with greater activation of the MPFC and attenuation of amygdala activity (Hariri, Bookheimer, & Mazziota, 2000; Taylor, Phan, Decker, & Liberzon, 2003).
Furthermore, activity of the amygdala is inversely associated with MPFC activity (Abercrombie et al., 1996; Liberzon et al., 2002). Therefore, given the MPFC’s reciprocal connections with the subcortical limbic structures, including the amygdala, researchers have postulated that the MPFC could act as a top-down regulator of intense emotional responses generated by the amygdala (Phan, Wager, Taylor, & Liberzon, 2004).

The ACC is also hypothesized to be involved with the cognitive components of emotional processing and may interact with the MPFC to regulate interconnected cognitive and emotional tasks (e.g., recognition or rating of emotional stimuli) (Phan et al., 2004). The ACC also appears to be preferentially important for the cognitive generation of affect (e.g., emotions induced by memories or imagery of affective events) (Teasdale et al., 1999). Finally, several studies suggest that the ACC mediates physiological arousal indexed by the galvanic skin conductance response and may be involved in regulating conflicting internal states (Critchley, Mathias, & Dolan, 2001).

**Amygdala.** The amygdala, located within the medial portion of the temporal lobe, is the primary brain region implicated in emotion. This subcortical limbic region consists of several nuclei, each of which can be partitioned into subnuclei. Additionally, each nucleus has unique inputs and outputs (LeDoux, 2007). A comprehensive discussion of the nuclei along with all their connections is beyond the scope of this review, therefore only a brief description of the primary nuclei and related functions is provided. As shown in Figure 2-14, the amygdala consists of the lateral, central and basal nuclei. The lateral nucleus is considered the gatekeeper, as it receives inputs from the sensory systems (i.e., visual, auditory, somatosensory, olfactory, and taste).
This sensory information influences behavior through the lateral amygdala’s intraconnections to the central and basal nuclei, which have strong output connections to other brain regions. The central nucleus, an important output region, controls physiological responses and emotional reactions (such as freezing) via connections to the brainstem. Finally, the basal nucleus is involved with the control of instrumental actions through connections with the ventral striatum.

The amygdala was originally hypothesized to be involved specifically in fear-related responding. Consistent with this notion, animal, lesion, and imaging studies have demonstrated that the amygdala is involved in detecting signals of threat (Isenberg, Silbersweig, & Engelien, 1999; Phillips, Young, & Scott, 1998; Scott et al., 1997) and coordinating the appropriate responses (King & Conway, 1992; Kulver & Bucy, 1939; Weiskrantz, 1956), generating fearful emotional responses (Halgren, Walter, Cherlow, & Crandall, 1978; Ketter, Andreason, & George, 1996), and maintaining fear-related emotions (Buchel & Dolan, 2000; LeDoux, 2000). More recent neuroimaging data indicates that the amygdala is also activated in response to appetitive stimuli (Garavan, Pendergrass, Ross, Stein, & Risinger, 2001; Hammann, Ely, Hoffman, & Kilts, 2002). Additionally, Phan et al. (2003) found that the perceived intensity of the emotional response positively correlates with amygdala activation. Therefore, the amygdala is now hypothesized to have a more general role for responding to salient stimuli, regardless of valence (Davis & Whalen, 2001).

**Periaqueductal Gray (PAG).** The PAG is considered the final common path for all defensive responses (Vianna & Brandao, 2003). Lesions of the PAG can permanently abolish defensive reactions (Graeff, 1994) or cause significant reductions
of innate (Blanchard, Williams, & Lee, 1981) and learned defensive behaviors (LeDoux, Iwata, Cichetti, & Reis, 1988). Furthermore, lesions of the PAG can abolish defensive responses induced by amygdala and hypothalamic stimulation, whereas lesions of the amygdala or hypothalamus do not block defensive reactions elicited by PAG stimulation (Graeff, 1994). The PAG consists of four main longitudinal columns: dorsal medial PAG (dmPAG), dorsal lateral PAG (dlPAG), lateral PAG (IPAG), and ventral lateral PAG (vIPAG). While the specific functions of these PAG subdivisions remain debatable, general hypotheses have been forwarded. The dlPAG is thought to be involved in regulating unconditioned fear responses (i.e., freezing and escape behavior) induced by immediate danger (Canteras, 2002). Furthermore, the dlPAG has dense reciprocal connections to the hypothalamic nuclei mediating defensive responses (Cameron, Khan, Westlund, Cliffer, & Willis, 1995; Vianna & Brandao, 2003). The vIPAG likely mediates responses of conditioned freezing and quiescence via direct and reciprocal connections with the central nucleus of the amygdala (Rizvi, Ennis, Behbehani, & Shipley, 1991; Vianna & Brandao, 2003). Lesions of the amygdala reduce conditioned fear responses, such as freezing and the potentiated startle response, but do not affect the freezing response to immediate danger (Antoniadis & McDonald, 2001). Less appears is known about the dm and IPAG. However, similar to the dlPAG, the dmPAG is likely involved in the unconditioned fear response. The IPAG has been linked to attack defensive behavior.

In addition to the dense reciprocal projections with the amygdala and hypothalamus, the PAG connects to the lower brain stem regions and the basal ganglia (Vianna & Brandao, 2003). The dlPAG has descending projections to the cuneiform
The dmPAG, IPAG, and vlPAG project to the caudal raphe nuclei located in the medial portion of the reticular formation. Stimulation of the caudal raphe nuclei elicits immobility (Morgan & Whitney, 2000). The vlPAG also sends direct projections to the motoneurons of the ventral horn of the spinal cord (Mouton & Holstege, 1994). The dPAG receives inhibitory GABAergic projections from the substantia nigra pars reticulate (SNpr) of the basal ganglia. Lesions of the SNpr have been shown to increase defensive responses elicited by stimulation of the dPAG (Coimbra & Brandao, 1993). As such, the SNpr likely exerts inhibitory control of the defensive behavior organized at the level of the midbrain tectum.

**Basal Ganglia.** The basal ganglia nuclei implicated in affective processes include the ventral striatum (nucleus accumbens), ventral pallidum, medial tip of the SNr, and medial tip of the STN. Neuroimaging studies have linked emotional processing, particularly related to reward and happiness, to increased neuronal activation in the ventral striatum and ventral pallidum. For example, several studies have found activation of the ventral striatum in response to happy faces (Morris, Frith, Perret, et al., 1996; Phillips, Bullmore, Howard, & Woodruff, 1998) and pleasant pictures (Lane, Chua, & Dolan, 1999). Additionally, increased cerebral blood flow in the striatum (head of caudate nucleus and putamen) has been positively associated with viewing highly arousing sexual stimuli in males (Redoute, Stoleru, Gregoire, et al., 2000). Similarly, Rauch et al. (1999) found increased activation of the ventral globus pallidus during sexual and competitive arousal, as indexed by physiological responses and subjective ratings. Furthermore, Kampe and colleagues (2001) demonstrated that the
perceived attractiveness of an unfamiliar face increased activation of the ventral striatum of the viewer when meeting the attractive person’s eye. Given the basal ganglia’s rich innervations of DA neurons, researchers have hypothesized that the ventral striatum is ideally located to respond to incentive reward motivation and to the attainment of positive affect, such as happiness, that results from the progression toward a desired goal (Davidson & Irwin, 1999).

The basal ganglia may also have a functional role in processing the withdrawal-related emotion of disgust. Neuroimaging studies show increased basal ganglia activity in response to facial expressions of disgust compared to other emotions (Phillips et al., 1998; Phillips, Young, et al., 1997). Additionally, patients with Huntington’s Disease and Obsessive-compulsive disorder, who have basal ganglia dysfunction, exhibit impaired recognition of facial expressions of disgust (Sprengelmeyer et al., 1997). Given the basal ganglia’s prominent role in motor behavior, the basal ganglia may coordinate appropriate action responses toward a desired goal, such as approaching pleasant stimuli and withdrawing from unpleasant stimuli. Several limbic circuits involving the basal ganglia have been proposed based on animal and human research. Given that a primary focus of this review is on a disorder of the basal ganglia (namely, Parkinson Disease), the limbic circuitry involving the basal ganglia will be reviewed in further detail. Knowledge of these circuits is crucial to understanding the emotional symptoms of PD resulting from basal ganglia dysfunction, as well as the potential integration of emotion into the motor circuit.

**Limbic circuits involving the basal ganglia**

Haegelen and colleagues (2009) proposed two limbic circuits involving the basal ganglia, along with the medial prefrontal cortex (anterior cingulated cortex (ACC), orbital
frontal cortex (OFC), septal area), amygdala, hippocampus, the centromedian-parafascicular nuclei of the thalamus, and the ventral tegmentum area (VTA). The limbic regions of the basal ganglia include ventral striatum [Nucleus accumbens (NAcc)], ventral pallidum, medial tip of the SNr, and medial tip of STN. In both circuits, the anatomically centrally located STN is considered a regulator of the limbic pathways. The first circuit consists of one of the five parallel and segregated basal ganglia-thalamocortical loops (Alexander & Crutcher, 1990; Alexander et al., 1986; Middleton & Strick, 2000), in which the higher and lower regions of the brain communicate with the basal ganglia (See Figure 2-15). The medial prefrontal cortex, including the ACC, OFC, septal area, and medial surface of frontal lobe, send excitatory dopaminergic projections to the NAcc of the ventral striatum. The ventral striatum sends GABAergic inhibitory projections to the ventral pallidum, a major output region of the limbic system, and the centromedial nucleus of the thalamus through the SNr. The thalamus sends excitatory projections back to the medial prefrontal cortex. In an indirect pathway, the STN receives inhibitory input from the ventral pallidum and excitatory glutamatergic input from the medial prefrontal cortex. The STN then sends excitatory glutamatergic projections to the SNr, which sends inhibitory projections to the thalamus. According to this model, a balance of the direct cortico-subthalamic and indirect cortico-striato-pallidal-subthalamic pathways controls emotional processes (Alexander et al., 1986).

Haegelen et al. (2009) proposed that a second circuit, involving the basal ganglia, amygdala, hippocampus, and the ventral tegmental area, plays a larger role in regulating emotional processes. In this circuit, the STN of the basal ganglia receives affective information from the limbic cortex (medial prefrontal cortex, amygdala,
hippocampus) through an indirect and direct pathway (See Figure 2-16). First, the medial prefrontal cortex (i.e., ACC, OFC, septal area) directly sends affective and motivational information to the STN, which has reciprocal connections to the ventral pallidum. The STN sends excitatory glutamatergic projections to the ventral pallidum, which in turn sends inhibitory projections back to the STN. In the indirect pathway, the medial prefrontal cortex excites the NAcc, which inhibits the ventral pallidum, possibly reducing the inhibition of the STN from the direct pathway. The STN relays affective information from the cortex to the VTA, via excitatory glutamatergic projections. The VTA sends excitatory dopaminergic input back to the STN. The VTA, a group of neurons located in the mesencephalon, is considered the origin of the mesolimbic dopaminergic pathway and highly implicated in natural reward circuitry and motivation (Haber, 2005). Thus, according to Haegelen et al., limbic information from the medial prefrontal cortex, indirect striatonigral pathway and the mesolimbic pathway (VTA) can be integrated and processed in the STN. As will be discussed in the Emotion and Movement section, emotion information from both limbic circuits may be integrated into motor basal ganglia circuitry.

**Emotion deficits in Parkinson disease**

The nigrostriatal neuronal degeneration in PD influences all pathway connections involving the SN and striatum, including the mesocorticolimbic dopaminergic pathways (Braak & Braak, 2000). Not surprisingly then, Parkinson Disease has been increasingly linked with emotional dysfunction. Indeed, impairments in emotional processing represent a distinct deficit in PD. PD patients often display monotonous, flat, and poorly inflated speech, and are recognized as exhibiting masked faces (i.e., blunted facial
expressivity) with the inability to make spontaneous emotional expressions (Ariatti, Benuzzi, & Nichelli, 2008).

Greater symptoms of apathy, depression, anxiety, and anhedonia (i.e., the inability to experience pleasure in normally pleasurable activities) also characterize PD. For example, Leentjens, Marinus et al. (2003) reported the prevalence rate of Major Depression in PD to be 20-25%. A clinic-based study of PD patients reported clinically significant depressive symptomatology in 57% of patients (Rojo, Aguilar, & Garolera, 2003). Furthermore, individuals with an affective disorder are at a greater risk of being diagnosed with PD compared to patients with osteoarthritis or diabetes (Nilsson, Kessing, & Bolwig, 2001). Apathy, often masked as depression, can occur with or without depression. Thus, although apathy is a characteristic feature of PD, the exact prevalence of apathy is difficult to determine. Similar to the rates of depression, 20-52% of PD patients exhibit clinically significant anxiety symptoms (Shulman, Taback, & Rabinstein, 2002). Anxiety may present as generalized anxiety disorder, phobias, or panic attacks. The presence of anxiety may exacerbate existing motor symptoms. For example, Adkin et al. (2003) found that fear of falling was associated with impaired postural instability in PD patients. While the mechanisms underlying the increased rates of depression, apathy, and anxiety in PD are not completely understood, researchers acknowledge that they are likely independent from the functional disability and motor deficits characteristic of PD (Leentjens et al., 2003). Neurodegeneration of subcortical nuclei and ascending DA, serotonin, and norepinephrine pathways within the basal ganglia-frontal circuits may play a critical role in producing depression and anxiety symptoms in PD (Remy et al., 2005). Remy et al., found that depressed PD patients
compared to non-depressed patients have a greater loss of dopaminergic and noradrenergic innervations in several regions of the limbic system, including the amygdala, thalamus, left ventral striatum, and ACC. Additionally, patients with greater anxiety symptoms had greater loss of dopaminergic and noradrenergic innervations in the amygdala and thalamus. Dopamine deficiency in the limbic areas may also be a cause of apathy (Czernacki, Schupback, & Regis, 2008).

A consistent feature of idiopathic PD is significant pathological changes in the amygdala. Harding et al. (2002) found a 20% reduction in total amygdala volume and high concentrations of lewy body formation, particularly in the basolateral amygdala. Furthermore, Ouchi et al. (1999) discovered that individuals with PD show up to a 45% decrease of dopamine agonist binding in the amygdala. Using fMRI, Tessitore et al. demonstrated that an emotional task was associated with bilateral amygdala activation in healthy subjects, but not in non-medicated PD patients. Importantly, dopaminergic repletion partially restored amygdala activation. The amygdala is not the only damaged structure of the limbic system found in PD, however. Mesolimbic dopaminergic networks are also damaged (Braak & Braak, 2000). Postmortem studies show that individuals with PD exhibit a 40% reduction in the number of ventral tegmental neurons (German et al., 1989), a 40-60% loss of cells in the VTA (Uhl, Hedreen, & Price, 1985), and a significant decrease in dopamine in the frontal cortex and hippocampus (Scatton, Rouquier, Javoy-Agid, & Agid, 1982). The amygdalar hypoactivity, resulting from reduced mesolimbic dopaminergic input from VTA, may cause the deficits in emotional expression and recognition found in PD.
The extant research suggests that PD patients exhibit impaired recognition of emotion from prosodic cues and facial expressions, with a selective and disproportionate deficit for the discrete emotions of anger (Lawrence, Goerendt, & Brooks, 2007), disgust (Dujardin, Blairy, Defebvre, et al., 2004; Suzuki, Hoshino, Shigemasu, & Kawamura, 2006), and fear (Ariatti et al., 2008; Dara, Monetta, & Pell, 2008). These deficits may be caused by dopamine loss in the basal ganglia-limbic circuits. Supporting this notion, Sprengelmeyer et al. (2003) showed that impaired recognition of disgust and anger from facial expressions can be partially attenuated by dopaminergic repletion. Furthermore, neuroimaging evidence has implicated a role of the basal ganglia in the processing of disgust and anger, as well as emotional prosody processes (Kotz, Meyer, Alter, et al., 2003; Wildgruber, Riecker, Hertrich, et al., 2005). Thus, a functional basal ganglia may be necessary for recognizing certain emotional meanings from the prosodic element of speech.

Several studies have indicated that individuals with PD show reduced psychophysiological reactivity to emotional stimuli. For example, Bowers and colleagues revealed that persons with PD, even while “on” medication, exhibit blunted startle eye blink magnitude to aversive pictures, while startle reactivity to pleasant pictures was similar to that of healthy controls (Bowers et al., 2006). Miller et al., (2009) later qualified these findings by revealing a lack of startle potentiation to only a specific subcategory of aversive pictures (mutilations). Similar startle reactivity in response to fear, pleasant, and neutral pictures was observed among control and PD patients. However, the authors suggested that mutilation pictures may have been the only category of aversive pictures sufficiently arousing to detect a deficit in emotional reactivity in PD patients.
Indeed, further analysis indicated that control subjects displayed greater eye-blink magnitude for highly arousing negative pictures relative to the low arousing negative pictures, whereas the PD patients did not exhibit changes in startle eye blink magnitude as a function of arousal level. The authors concluded that blunted physiological response to highly arousing aversive stimuli is likely caused by the inability of individuals with PD to translate an aversive motivational state into a physiological response. Startle circuitry involves projections of the amygdala to structures in the brain stem. The prefrontal cortex typically exerts inhibitory control over the amygdala (Rosenkranz & Grace, 2002), until stress-induced DA release in the basolateral amygdala suppresses this inhibition (Marowsky, Yanagawa, Obata, & Vogt, 2005). These findings prompted Bowers, Miller, and colleagues (2006, 2009) to postulate that dopamine depletion, evidenced in PD, would reduce the disinhibition of the amygdala in response to stressful stimuli, thereby inhibiting startle reactivity.

While research has examined the impact of emotion on involuntary movement in PD, whether emotion impacts voluntary movement in PD patients the same way as healthy controls remains unexplored. The current study will examine PD patients’ voluntary motor reactivity to affective stimuli, as indexed by the initiation of gait.

**Summary**

Two limbic circuits involving the basal ganglia regulate emotional processes. PD is characterized by dopaminergic and noradrenergic denervation of limbic-basal ganglia pathways, as well as pathological changes in the amygdala. Dysfunction in these circuits likely underlies emotional symptoms in PD, such as high rates of apathy and depression, impaired recognition of emotion from prosodic cues and facial expressions, and reduced physiological reactivity to emotional stimuli. Despite the recognition that
motor behavior an important component of the affective experience, it is surprising that researchers have largely ignored the implications of impaired emotional functioning on motor behavior in PD. The impact of emotion on movement will now be discussed in detail.

**Emotion and Movement**

A growing body of literature supports the long held notion that human emotion and motor actions are largely intertwined and reciprocally interrelated (Niedenthal, 2007). Affective theorists traditionally agree that emotions prime or facilitate action (Frijda, 2009; Frijda, Kuipers, & ter Schure, 1989; Lang, 1995), motivating behavioral responses to approach pleasant and avoid unpleasant stimuli and situations. The motivational direction hypothesis is founded on the principle that unpleasant emotions activate defensive circuitry and prime avoidance behaviors (although anger is one exception: Harmon-Jones & Allen, 1998; Harmon-Jones, Harmon-Jones, Abramson, & Peterson, 2009), whereas pleasant emotions activate appetitive circuits that prime approach behaviors (Cacioppo, Priester, & Berntson, 1993; Centerbar & Clore, 2006; Chen & Bargh, 1999; Duckworth, Bargh, Garcia, & Chaiken, 2002). In the early 1990s, researchers began to explore the influence of emotion on approach- and avoidance-related movements. Such evidence has typically been acquired using protocols that manipulate emotional states prior to or during the execution of arm movements which are made toward or away from the body. Inferences have been drawn from these data regarding the interdependence of emotion and approach/avoidant behavior based on several different theoretical approaches, including muscle activation, distance regulation, evaluative coding, and embodiment accounts. These theories will first be reviewed in detail, as they potentially have important implications concerning the impact
of emotional state on any directional movement, including gait initiation toward or away from an affective stimulus. An overview of the evidence for emotional modulated movement which is not focused on direction-specific movements will follow. Such movements include involuntary postural adjustments, pinch grip tasks, and motor cortex excitability. Finally, the possible neural circuitry responsible for integrating emotional and motor systems will be discussed.

Emotion Modulated Movement - Approach and Avoidance Movements

Muscle activation accounts assume that specific motor responses manifest as approach and avoidant behaviors. Unpleasant emotional cues have routinely been found to facilitate arm extension movements, while pleasant emotional cues facilitate arm flexion. This link is typically explained by a form of higher order Pavlovian conditioning, in which long term associations are formed between arm flexion and approaching an object (i.e., the consumption of desired goods). Additionally, an association is formed between arm extension and avoiding an aversive object (Cacioppo, Priester, & Berntson, 1993; Neumann & Strack, 2000). Several studies have provided a direct link between evaluation of an affective object and approach and avoidance behavior, as defined by flexion and extension arm movements, respectively (Cacioppo et al., 1993; Chen & J.A. Bargh, 1999; Duckworth et al., 2002; Forster & Strack, 1996; Neumann & Strack, 2000). For example, Chen and Bargh (1999) examined whether automatic affective evaluation primed activation of approach and avoidance muscular tendencies. One group of participants was instructed to push a lever away from them (extension movement) in response to negatively evaluated stimulus words and to pull the lever towards them (flexion movement) in response to positively evaluated stimulus words. Another group of participants was given the
opposite instructions. As hypothesized, the intentional evaluation of a stimulus as positive facilitated flexion (pull) relative to extension (push) movements, and the negative evaluation of a stimulus speeded extension relative to flexion arm movements. A second experiment removed the task instructions of evaluating the stimulus words. Thus, participants were required to push or pull the lever in response to stimulus presentation, irrespective of affective meaning. The results replicated experiment 1, suggesting that affective processing automatically and unconsciously motivates approach and avoidance response tendencies. Duckworth et al., (Experiment 3; 2002) further supported Chen & Bargh’s position that the link between affective evaluation and behavioral tendency is non-conscious. Similar to experiment 2 of Chen and Bargh, pushing or pulling a lever in response to the mere presence of novel, affectively valenced stimuli generated muscular predispositions to approach positive stimuli (flexion) and avoid negative stimuli (extension).

Evidence suggests that the relationship between muscular tendencies and affect is bidirectional. Cacioppo, Priester, & Berntson (1993) showed that bodily positions influence evaluation of affective stimuli. Specifically, participants gave a more positive evaluation of presented stimuli when their arm was simultaneously flexed rather than extended. Additionally, Forster and Strack (1996) demonstrated that performing arm flexion enhanced the recall of positively compared to negatively evaluated information, whereas performing arm extension tended to enhance the recall of negatively evaluated information relative to positive and neutral.

Rotteveel and Phaf (2004) further investigated whether affective stimuli automatically and unconsciously prime corresponding action tendencies. In contrast to
previous studies, button presses rather than lever movements were used to induce arm flexion and extension. Participants were instructed to push a lower (extension) or upper (flexion) button on a vertical stand in response to the emotional valence of angry or joyful facial expressions. Similar to Chen and Bargh, the affect-congruent conditions (joy faces - arm flexion and angry faces - arm extension) generated shorter latencies than the affect-incongruent conditions (joy faces - arm extension and angry faces - arm flexion). However, a second experiment drawing participants’ attention to the non-affective features (e.g. gender) of valenced faces failed to reveal an influence of affect on the corresponding action tendencies. Thus, the authors concluded that the link between affect and arm flexion and extension may depend on the *intentional* goal of evaluating the affective properties of a stimulus.

Importantly, later studies have yielded inconsistent results regarding the classification of arm flexion and extension as representing approach and avoidance movements, respectively (Lavender & Hommel, 2007; Markman & Brendl, 2005; Neumann & Strack, 2000; Wentura, Rothermund, & Bak, 2000). Neumann and Strack (Experiment 2; 2000) sought to determine whether approach and avoidance behavior could be conceptualized as behavior that regulates the distance toward important objects. Thus, the reduction of spatial distance toward an object would be considered approach, while increasing spatial distance from an object would be interpreted as avoidance. To test this distance regulation hypothesis, the authors induced the visual illusion that participants were either moving toward or away from the computer screen while they were evaluating the valence of positive and negative adjectives. As predicted, participants were faster to categorize positive adjectives when they had the
impression of moving toward the screen and faster to categorize negative adjectives when they had the impression of moving away from the screen. Replicating these results in the absence of the goal of affective evaluation (Experiment 3), the authors concluded that 1) affective information is perceived automatically from a stimulus without conscious evaluation, and 2) approach and avoidance behavior can have many manifestations.

Similarly, Markman and Brendl (2005) demonstrated distance regulating effects in approach and avoidance behavior while also revealing that body movements are made relative to a person’s representation of the self in space rather than his/her’s physical location. The authors constructed a variant of the Chen and Bargh task in which participants’ representation of the location of the self in space was decoupled from the representation of their body in space. Positive and negative words were presented either further away or nearer to the name of the participant that was placed in the center of a corridor receding in depth on a computer screen. In half of the trials, participants were instructed to move the words (with a joystick) toward their name if the word was positive and away from their name if the word was negative. In the other half of the trials, participants were instructed to do the opposite. Participants were faster to move positive words toward their name on the screen than away from their name, with the opposite pattern of results found for movements in response to negative words. Importantly, this pattern of results was found regardless of whether the response required an extension (e.g., pushing a positive word toward representation of self on screen) or flexion (e.g., pulling a negative word away from the representation of self) arm movement.
Research has also shown that the manifestation of approach and avoidance behavior is mediated by the intentions and goals of the acting individual. Lavender and Hommel (2007) systematically pitted the influence of arm flexion/extension response tendencies against cognitively based, goal-dependent response tendencies. Similar to Markman and Brendl (2005), the authors argued that the goals of the action, rather than the specific muscle activations, modulate the compatibility between affective stimuli and behavioral tendencies. In this study, participants were instructed to move a doll toward (approach) or away (avoidance) from a computer screen as quickly as possible in response to the presentation of affective pictures. Pictures were either unpleasantly or pleasantly valenced and slightly rotated either to the left or right. Half of the participants were instructed to evaluate the affective valence of the picture, while the other half evaluated the spatial orientation of the picture. Additionally, half of the affective instruction group was instructed to make avoidance movements in response to negative pictures and approach movements in response to pleasant pictures. The other half received reversed instructions. Participants receiving spatial instructions were asked to make an avoidance movement in response to left-oriented pictures, and an approach movement in response to right oriented pictures. Again, the other half of participants received reversed instructions. Thus, based on the goals of the action, the authors hypothesized that pleasant stimuli should facilitate movement toward the screen (requiring arm extension), whereas unpleasant stimuli should facilitate movement away from the screen (requiring arm flexion). Alternatively, if muscle activation patterns play a stronger role than cognitive interpretations of movements, then the opposite pattern of results should be found. The results confirmed the former hypothesis: pleasant stimuli
facilitated arm extension (approach goal) and unpleasant stimuli facilitated arm flexion (avoidance goal). Thus, the arm movements provided ambiguous behavioral measures, rather than default measures of approach and avoidance as postulated by muscle activation accounts. Furthermore, supporting Rotteveel and Phaf (2004), participants receiving the spatial-focused instructions failed to demonstrate any affective stimulus-response relation. Lavender and Hommel concluded that the cognitive representation of actions, as well as the presence of an affective evaluation goal, determines whether a given muscle movement is coded as approach or avoidance.

Eder and Rothermund (2008) proposed an evaluative-response coding view of approach and avoidance reactions in an attempt to resolve the inconsistencies concerning which specific motor responses manifest as approach and avoidance behavior. This approach is based on three primary assumptions, which explain how identical motor reactions can be positively coded in one context and negatively coded in another. First, similar to Lavendar and Hommel’s ideas, the evaluative coding approach assumes that the evaluative implications of action instructions and goals assign affective codes to motor responses on a representational level. Thus, the representation of approach behavior should be linked to a positive response code, while the representation of avoidance behavior should be linked to a negative response code. Secondly, motor action codes consist of a network of distributed feature codes, specifying properties of the action on several dimensions (e.g., evaluative dimension). Therefore, the affective value of motor representations is flexibly set based on current goals and relevant situational constraints. Third, response labels (e.g., toward v. away) used in task instructions and relevant semantic action knowledge may directly
determine the codes controlling instrumental behavior. For example, labeling the pull of a lever as an away or downwards movement should assign a negative code to the movement, where as labeling the identical movement as towards oneself or upwards would assign a positive code to the lever pull.

Eder and Rothermund conducted a series of experiments testing the evaluative response coding approach against the muscle activation and distance regulation approaches. In the first experiment, response labels of towards-away and up-down were given to lever push and pull movements. A preliminary study indicated that the word up was judged more positively than down and toward more positively than away. Participants used the push/pull movements of the lever to classify the valence of positive and negative words. One group of participants was instructed to pull the lever toward them or downward in response to positive words and to push the lever away from them or upward in response to negative words. The other group of participants received the reverse instructions. The toward-away labels replicated the standard positive-pull/negative-push effect found in studies supporting the muscle activation account. However, the upward/downward labels produced the reversed effect. The downward label elicited a slower pull movement (flexion) in evaluation of positive stimuli, while the upward label elicited a slower push movement (extension) in evaluation of negative stimuli. The results supported the notion that flexion and extension arm movements are not sufficient to explain valence modulations of lever movements (Lavender & Hommel, 2007; Markman & Brendl, 2005). Experiment 2 tested the predictions of the distance regulation hypothesis against the evaluative coding explanation. Using an experimental set-up similar to Lavender and Hommel,
participants were instructed to move the lever towards or away from the evaluated stimulus on the computer screen. As in experiment 1, another group of participants was instructed to move the lever downwards (push) and upwards (pull) in response to the evaluated stimulus. Supporting distance-regulation accounts (e.g., Neuman & Strack, 2000), instructions to move toward the evaluated stimulus (extension) speeded evaluations of positive words, while instructions to move away (flexion) from the evaluated stimulus speeded evaluation of negative words. The reverse effect was once again found for the upward/downward instructions. Taken together, experiments 1 and 2 indicated that the positive and negative evaluative connotations of the response labels (toward/up-positive, away/down-negative) modulated the facilitation of arm push and pull lever movements. Experiment 3 extended the findings to left and right lever movements; movements that by themselves were unrelated to approach/avoidance or distance regulation. For example, labeling of left and right lever movements with positive connotations (upwards or towards) facilitated movements in positive evaluations. Overall, these experiments support the evaluative response coding view of approach and avoidant reactions, suggesting that the valence of movements toward and away from a reference point is reliant upon the evaluative connotation of the response labels used to guide these behaviors. The evaluative coding view can thereby accommodate a diverse set of empirical findings that were originally interpreted through more specialized theoretical accounts of approach and avoidance behavior (e.g., muscle activation, distance regulation). Importantly, Eder and Rothermund suggested, however, that specialized accounts should not be completely dismissed because they
likely shed light on the reasons why behaviors are coded in a certain way in a specific situation.

Recently, embodiment views of emotion have provided another promising explanation for the relationship between bodily states of emotion (e.g., arm flexion/extension, facial expressions, posture) and the processing of emotional information (Niedenthal, 2007; Niedenthal et al., 2005; Niedenthal, Mondillon, Winkielman, & Vermeulen 2009). As previously discussed, embodiment accounts postulate that the processing of emotional information involves the ability of the sensory-motor systems to partially reenact aspects of the original states that occurred when the emotion was experienced. According to this viewpoint, conceptual representations (i.e., emotional meaning) of approach and avoidance behavior are originally encoded from concrete sensory-motor experiences. As such, emotion concepts can be represented by simulations of approach and avoidance behavior. Several studies supporting the embodiment view have shown that performing actions with a particular valence (e.g., smiling v. frowning) results in compatibility effects in subsequent evaluations (Niedenthal et al., 2009; Oberman, Winkielman, & Ramachandran, 2007; Strack, Martin, & Stepper, 1988). For example, Strack, Martin & Stepper (1988) required participants to hold a pencil with their front teeth or between their lips while evaluating the funniness of different cartoons. Holding the pencil with their teeth facilitated a smile, while holding the pencil between their lips inhibited a smile. Participants who “smiled” rated the cartoons funnier than those whose smiles were inhibited. In a similar study, participants who were prevented from engaging expression-relevant facial muscles (i.e., biting a pen) exhibited impaired recognition of
happy facial expressions (Oberman et al., 2007). Thus, recognition performance was maximized when the perceived emotion was congruent with the participants’ bodily state. This same concept has been used to explain how approach (i.e., moving the lever toward a reference point) and avoidant lever movements (moving the lever away from a reference point) are facilitated by positive and negative valenced conditions, respectively. For example, the embodiment view postulates that the processing of positively-valenced emotional information is at least partially grounded in the motor states involved in approach responses, such as pulling a lever toward the body or pushing a lever toward pleasant stimuli. Similar to the evaluative coding explanation of affective mapping effects, embodiment theories of emotion stress the importance of contextualized, situated representations of approach and avoidant behavior allowing for some flexibility in the link between valence and specific body movements.

As briefly alluded to in the Emotion section, another controversial issue in the emotion and movement literature involves the congruence of unpleasant stimuli with withdrawal motivation. Research has revealed that not all aversive stimuli facilitate avoidance-related behavior. For example, fear expressions, rated as appearing highly submissive and as equally affiliative as happy expressions (Hess, Blairy, & Kleck, 2000) have been shown to predominantly elicit approach-related responding (Marsh, Ambady, & Kleck, 2005). Specifically, Marsh et al. instructed participants to push or pull a lever in response to anger and fearful facial expressions. As expected, participants exhibited faster pushing (avoidance) relative to pulling lever (approach) movements in response to angry faces. However, fearful faces, although also unpleasant in valence, elicited faster approach-related pulling movements. Fearful faces may elicit caregiving or
empathy from observers and consequently represent an affiliative stimulus. Collectively, the authors interpreted the behavioral responses as emotion specific rather than reflecting broad valence dimensions. In contrast to the Marsh study, several lines of research have shown that anger, although negative in valence, elicits approach motivational tendencies (See Carver & Harmon-Jones, 2009 for a review). For example, research has shown that anger is associated 1) with attack, an approach behavior (Berkowitz, 1993) and 2) with relative left-prefrontal activation (associated with approach motivation) (Harmon-Jones & Allen, 1998). Furthermore, trait anger has been linked to greater assertiveness and competitiveness, traits associated with approach-related motivation (Buss & Perry, 1992). Thus, extant research suggests that fearful facial expressions and anger appear to defy this relationship of valence and motivational direction.

Also seeking to understand the relation between affective valence, motivational direction, and behavior, Coombes and colleagues (2007) examined the peripheral and central components of a wrist extension movement during exposure to affective stimuli representing specific unpleasant affective categories (i.e., attack, mutilation). Participants demonstrated speeded premotor reaction times (reflecting central processes) for extension movements initiated during exposure to attack pictures relative to all other categories (mutilation, erotic couples, opposite-sex nudes, neutral humans, household objects, blank). While the authors concluded that unpleasant states do not unitarily prime withdrawal movements, this interpretation of the results needs to be taken with caution. As discussed above, recent conceptual efforts have shown that movements should not be classified into approach/withdrawal-related behavior based
solely on muscle activation patterns, such as extension and flexion. Importantly, the authors also noted that an accelerated motor response to threatening stimuli offers organisms an advantage in dangerous environments, supporting the notion that the emotion system has evolved to prime organisms to react to stimuli in a way that promotes survival (Öhman, Hamm, & Hugdahl, 2000; Öhman, & Soares, 1998). Thus, as an alternative interpretation of the results, exposure to extremely threatening stimuli compared to other valenced stimuli may speed the initiation of movement (regardless of movement direction), motivated by one of the most primitive and fundamental goals of survival. This notion is further supported by research showing that exposure to attack pictures compared to erotic, mutilation, and neutral pictures speeds reaction times on a non-directional goal-directed ballistic pinch grip task (Coombes et al., 2009). Taken together, the Coombes et al. studies and others demonstrate that the categorization of affective stimuli into broad valenced, rather than emotion-specific categories is likely not sufficient for a comprehensive understanding of emotion modulated movement.

While contemporary affective scientists have admirably attempted to understand the interaction of motivational priming and the direction of intended movement, these conceptual efforts have been limited by their focus on such a small range of movements (e.g., facial expressions and arm movements). Until recently, the influence of emotional state on voluntary whole body movements remained unexplored. Addressing this limitation, Gamble et al. (in review) investigated the influence of emotional state on forward gait initiation. Requiring participants to walk toward or away from the presentation of an affective stimulus clearly indexes an approach or avoidant behavior, thereby removing the directional ambiguity found in previous work. Participants initiated
gait in response to the offset of emotional stimuli and continued to walk toward the location of the presented stimuli. The authors were therefore able to explore the impact of unpleasant and pleasant stimuli on a purely approach-related behavior. As expected, exposure to high and low arousing pleasant stimuli facilitated the COP movements and execution of the first step. Interestingly, however, the high arousing unpleasant pictures (attack) compared to all other conditions, speeded reaction times on the gait initiation task, despite the movement clearly being approach-oriented. This result supports the notion that faster movements, regardless of direction, are primed in threatening situations. Collectively, the authors concluded that highly arousing unpleasant conditions accelerated the initiation of a motor response, but as the direction of the movement emerged, the pleasant conditions relative to the unpleasant ones, clearly facilitated the initiation of gait. While this study was a first step in exploring the impact of emotion on voluntary whole body movements, much work remains. For example, future research needs to investigate 1) the influence of more specific emotion categories on gait initiation, 2) how emotion impacts gait initiation, conceptualized as an avoidance behavior, and 3) how dispositional differences in emotional reactivity interact with emotional state to influence specific gait initiation parameters.

**Emotion Modulated Movement – Nondirection Specific Movements**

The emotion-movement database has grown considerably in the last decade with researchers beginning to investigate the influence of emotion on aspects of human movement not just related to approach or avoidant behavior. Collectively, this evidence also supports the notion that emotions prime or facilitate action.

Hajcak et al. (2007) used transcranial magnetic stimulation to directly investigate the influence of passively viewing emotional stimuli on motor cortex excitability. The
magnitude of muscle-evoked potentials (MEPs) elicited in the abductor pollicus brevis muscle was measured while participants viewed pleasant, unpleasant, and neutral pictures. The TMS-induced MEP was greater while participants viewed the highly arousing pleasant and unpleasant pictures relative to the neutral. Thus, the intensity of emotional states, regardless of valence, increased motor cortex excitability. Behavioral evidence also supports the notion that emotional arousal, rather than valence, modulates non-directional movements. For example, Coombes et al. (2008) recently studied the impact of picture induced affect on a precision pinch grip task. Participants sustained a pinch grip force at 10% of maximum voluntary contraction while receiving online feedback. After a short interval, feedback was replaced with either a pleasant, unpleasant, or neutral IAPS picture. Following removal of feedback, force production decayed in all conditions. However, exposure to the more arousing pleasant and unpleasant images similarly reduced the magnitude of decay relative to the less arousing neutral images. Gamble et al. (in review) later replicated and extended these results at the 2% and 35% target force levels, while additionally finding that self-report judgments of valence and arousal predicted force output on the pinch grip task. Interestingly, at the 35% target force level the relationship between affective state and force control varied according to individual differences in depression. This effect of depression on force control was only evident shortly following picture presentation and disappeared as time progressed.

Coombes et al. (2009) also demonstrated the importance of considering the influence of the trait component of the affective experience on motor behavior. Specifically, participants high and low in trait anxiety executed a ballistic goal-directed
pinch grip task at 10% or 35% of MVC at the offset of emotional and neutral pictures. The high trait anxiety group compared to low trait anxiety group exhibited slower reaction times on the pinch grip task at 10% of MVC, regardless of the affective condition. No differences were found for the pinch grip at 35% of MVC. Taken together, the our prior work has demonstrated that the characteristics of the task (e.g., target force level), the nature of the emotion eliciting stimuli, as well as individual differences in affective reactivity all appear to modulate force and speed-related parameters of a subsequent movement.

While the upper extremity remains a favored target area for research examining emotion modulated movement, emotion evoked postural adjustments during quiet standing have also been studied. For example, Hillman, Rosengren, & Smith (2004) required participants to view pleasant, unpleasant, and neutral pictures while quietly standing on a force plate. The results revealed that females exhibited increased center of pressure (COP) movement in the posterior direction (i.e., away from pictures) when viewing unpleasant pictures, whereas males demonstrated modest posterior postural sway under such conditions. The authors suggested that the increased posterior movement was motivated by behavioral withdrawal from the unpleasant stimuli, and may reflect early preparation for the initiation of a “fight or flight” response. Contrary to expectations, neither males nor females demonstrated a COP shift toward pleasant pictures. Conflicting findings were reported by Azevedo and colleagues (2005), however, who revealed that passive viewing of mutilation pictures reduced overall body sway in the medial-lateral direction (i.e., standard deviation of COP trajectory) in male participants. Corroborating Hillman et al.’s suggestion of the underlying mechanism,
however, Azevedo et al. postulated that reduced sway also reflected the activation of a withdrawal response as evidenced by “freezing behavior.”

Methodological differences regarding the gender of participants, size of pictures, and outcome measures may have accounted for the contrasting withdrawal responses to unpleasant pictures in these two studies (i.e., increased freezing vs. increased posterior movement). For example, Hillman’s measure of interest was the displacement of the COP in the anterior-posterior direction, while Azevedo focused on the standard deviation of the COP displacement and the mean position. Hillman also presented pictures much greater in size than Azevedo, which could have led to larger effects. Finally, Hillman found the greatest modulation of postural responses to unpleasant stimuli in females, while Azevedo only assessed male participants. Nonetheless, these two studies demonstrated that unpleasant emotions are associated with specific postural adjustments.

In sum, variation in emotional state has been putatively associated with modulation of motor action. TMS evidence indicates that increases in emotional arousal (intensity) lead to greater primary motor cortex excitability when actively and passively viewing emotional images. Behavioral evidence demonstrates that emotion significantly influences basic central and peripheral parameters underlying single joint parameters and whole body movements. Collectively, the data suggest that motor system is not segregated from affective processes; indeed such processes are largely desegregated and integrated. The potential mechanisms underlying the integration of emotion into motor processes are discussed next.
The Integration of Emotion and Motor Processes

Based on animal research, Haber and colleagues (2003, 2009) have proposed three mechanisms through which information can be channeled from limbic to motor circuits. First, the axons and dendrites within each structure of the basal ganglia often cross functional domains, allowing distal dendrites from one functional region to invade adjacent functional regions. Thus, activation of basal ganglia regions of the emotion circuit (i.e., ventral GP, ventral striatum) may also activate basal ganglia regions associated with the motor circuit (i.e., GPi, dorsal striatum). Secondly, the basal ganglia pathways consist of two neural networks, composed of complex non-reciprocal connections, which allow a continuous feedforward mechanism of information flow from limbic-circuits to motor circuits (Haber, Fudge, & McFarland, 2000; Joel & Weiner, 1997; McFarland & Haber, 2000). These two pathways, thalamo-cortico-thalamic and striato-nigro-strial, are reviewed in further detail.

The thalamo-cortico-thalamic pathway

As previously mentioned, the basal ganglia form several segregated, functionally organized pathways with the frontal cortex, in which functionally defined regions of the frontal cortex terminate topographically in the basal ganglia structures, which in turn project back to the cortex via the thalamus (Middleton & Strick, 2000). The functional regions of the frontal cortex are organized in a hierarchical manner and include the orbital and medial prefrontal cortex (OMPFC – emotion and motivation), dorsolateral prefrontal cortex (DLPFC – higher cognitive processes), and premotor and motor areas (motor planning and execution). Additionally, regions within each basal ganglia nuclei are associated with specific basal ganglia-cortical pathways (ventral → emotion; central → cognition; dorsolateral → motor), with the pathway involving the motor cortex
considered the final step to action (Fuster, 2001). Studies on primates and rodents now provide evidence that information from these parallel segregated basal ganglia-cortical circuits indeed influence each other (Haber & Calzavara, 2009). Specifically, thalamo-cortico-thalamic projections are in an ideal position to integrate information across functional basal ganglia-cortical loops. In these loops, the thalamus relays information from the basal ganglia to the cortex. McFarland & Haber (2002) revealed that the thalamic pathway back to the cortex has one component reinforcing each basal ganglia-cortical circuit, and another component which relays information between circuits via nonreciprocal corticothalamic pathways and through the organization of thalamic projections to different cortical layers.

As demonstrated in Figure 2-17, the thalamus projects to the superficial (layers I/II), middle (layers III/IV), and deep (layers V) cortical layers (McFarland & Haber, 2002). The thalamic projections to layer V continue the processing of information in each specific basal ganglia-cortico system via corticothalamic and corticostriatal loops. Furthermore, terminals in layer V interface with other circuit systems through a nonreciprocal projection to a thalamic region part of another cortical circuit system. Thalamic projections to layer I/II interface with corticocortical connections from layer III, also influencing adjacent basal ganglia-cortico circuits.

Haber proposed a schema illustrating how cognitive and affective information can be integrated across functional basal ganglia-cortical circuits via thalamic relay nuclei linking functionally adjacent frontal cortical areas (Figure 2-18). A feedforward pathway, beginning with the nonreciprocal projection from the sensory/limbic frontal regions to the MD thalamus likely channels affective information from limbic cortices to higher
association cortical areas (Jones, 1998). The central MD thalamic nuclei have reciprocal connections with the DLPFC, forming part of the associative basal ganglia-cortico loop. The VA receives input from the DLPFC, while also having reciprocal connections with the caudal motor and rostral motor areas involved in the cognitive aspects of motor action (e.g., planning). Thus, the VA thalamic nuclei relay information from the DLPFC to the caudal and rostral motor areas. Finally, the rostral motor cortices feedforward information to the VLo thalamic nuclei, which reciprocally connect to the primary and secondary motor cortices. In sum, information can be relayed from the limbic system to the motor system through these nonreciprocal corticothalamic feedforward pathways, shaping final motor output.

The striato-nigro-striatal (SNS) pathway

Research on rodents provided the first evidence that the limbic pathway could influence motor output via the SNS pathway, in which the ventral striatum modulates the dorsal striatum through midbrain dopamine neurons (Nauta, Smith, Faull, & Domesick, 1978; Somogyi, Bolam, Totterdell, & Smith, 1981). As demonstrated in Figure 18, a functional gradient from limbic (red) to associative (green) to motor (blue) domains is imposed on both the cortical projections to the striatum and on the three components of each striatal region (VMS- ventral medial striatum; CS – central striatum; DLS – dorsolateral striatum). The VMS consists of shell and core subdivisions (Kunishio & Haber, 1994; Lynd-Balta & Haber, 1994). The medial prefrontal cortex, receiving dense innervations from the orbital prefrontal cortex, amygdala, and hypothalamus, terminates on the shell of the VMS (Freedman, Insel, & Smith, 2000; Fudge et al., 2002; Kunishio & Haber, 1994). Additionally, the VMS receives direct projections from the amygdala and hippocampus (Fudge et al., 2002). The DLPFC projects to the rostral striatum,
mediating working memory and planning processes (Goldman-Rakic, 1996; Haber, 2003), whereas projections from the motor cortex terminate in the DLS (McFarland & Haber, 2000).

Interactions between the functional regions of the striatum occur through spiraling ascending midbrain connections. Midbrain DA cells terminate on the striatum while also receiving projections from the striatum. These DA midbrain cells are divided into a dorsal tier and a ventral tier (Francois, Yelnik, Percheron, & Fenelon, 1994; Haber et al., 1995). The dorsal tier includes cells from the VTA and SNc, while the ventral tier includes cells of the SNr. Forming an inverse dorsal-ventral topographic organization, cells of the dorsal tier project to the VS and CS, while cells of the ventral tier project to the DLS (Francois, Yelnik, Tande et al., 1999; Haber, Fudge, & McFarland, 2000; Haber et al., 1994). Additionally, the ventral medial striatum projects to the VTA and the medial SNc, as well as the medial pars reticulata. The CS projects more ventrally and in the pars reticulata region, while the DLS projects to the ventral regions of the midbrain in the SNr. Importantly, the ascending and descending striatum-midbrain dopamine connections in each functional area differs in their proportional projections. For instance, the ventral striatum projects to a large midbrain region, influencing a wide range of DA neurons. However, the VS receives input from only a limited midbrain region. Conversely, the DLS receives a large DA midbrain input, while projecting to only a limited midbrain region.

Each striatal region consists of three components as illustrated in Figure 2-19: 1) midbrain cells dorsal to its reciprocal terminal field (first oval – non reciprocal component), 2) midbrain cells lying within its reciprocal terminal field (second oval –
reciprocal component), and 3) ventral region of midbrain cells composed of nonreciprocal terminals (third oval - nonreciprocal component). Importantly, this third component overlaps with cells of the subsequent dorsal SNS system. Taken together, each striatal region consists of one reciprocal connection and two non-reciprocal connections with the midbrain. The nonreciprocal connections create an overlapping system in the midbrain, resulting in feedforward spiraling projections from ventral to dorsal striatal regions.

Through a series of spiraling connections, as demonstrated in Figure 2-20, information from the limbic system can reach the motor system. The shell of the VS sends information primarily from the amygdala and hippocampus to the midbrain, terminating in the VTA and SNc of the dorsal tier (red arrows). The VTA projects back to the shell, forming a closed SNS reciprocal loop. However, the shell region also projects to an area of the medial SN (i.e., lateral and dorsal to the dorsal tier) which feeds forward information to the core (orange and yellow arrows). Thus, this spiraling connection with the midbrain allows information from the shell to influence the core. The core, also receiving input from the OMPFC, has a reciprocal connection with the medial SN and projects ventral of its reciprocal component to the densocellular region of the dorsal tier. The CS interfaces with the core, via a reciprocal loop with the densocellular region (green arrows). Thus, information is transferred from the core to the CS. The CS also has a non-reciprocal projection to the ventral SNr and the cell columns, which are reciprocally connected to the DLS (blue). Thus, the transfer of information continues from the CS to the DLS and final motor outcome. Taken together, a series of ascending
spiraling connections through the different functional regions of the striatum and midbrain allow the ventral striatum to influence the dorsal striatum of the motor system.

In support of Haber's theory, animal and clinical research (See Salamone et al., 2007 for a review) indicates that circuitry involving the striatum, and more specifically the NAcc, as well as the VTA, amygdala, and frontal cortex may be particularly important in regulating behavioral activation (i.e., the energizing effects of behavior produced by motivational conditions). A primary method for studying behavioral activation is to measure locomotor activity in rats following psychomotor stimulants. NAcc depletions (Kelly, Seviour, & Iversen, 1975) and intra-NAcc injections of haloperidol have been shown to suppress rat locomotion, while injections of stimulants into the NAcc have been shown to increase locomotor activity (Delfs, Schreiber, & Kelley, 1990). Additionally, Baldo et al. (2002) found that D1 and D2 antagonists injected into either the shell or core of the NAcc suppressed locomotor activity. These studies are consistent with the notion that the NAcc may act as an interface between limbic areas involved in emotion and the components of the motor system controlling behavioral output (Mogensen, Jones, & Yim, 1980; Salamone et al., 2007).

In sum, research on primates has provided substantial evidence that parallel emotion and motor circuits interact via striato-nigral-striatal and thalamo-cortico-thalamic networks, channeling information from limbic to cognitive to motor circuits. Hypotheses derived from these integrated models have yet to be tested in humans. Thus, how emotion and motor systems interact in the human brain remains largely unspecified.
Emotion, Movement, and PD

Parallel emotion and motor circuits ensure that execution of specific behaviors are maintained and focused. Importantly, integration of these parallel circuits is necessary to adapt and modify motor behavior based on the affective state of the individual. Thus, parallel and integrative emotion and motor circuits must work together to coordinate behavior. As applied to bipedal locomotive behavior, emotional information from limbic basal ganglia circuits could potentially influence the initiation of gait through both the basal ganglia-thalamocortical system and the basal ganglia-brainstem system. As demonstrated in Figure 2-21, thalamic-cortico-thalamic pathways integrate limbic and motor basal ganglia-thalamocortical circuits, allowing emotional input to impact the volitional aspects of locomotion, including gait initiation. Additionally, limbic input could be integrated into the motor region of the striatum via midbrain dopaminergic neurons of the SNS pathway. Through this mechanism, limbic input could influence the basal ganglia-thalamocortical system and the basal ganglia-brainstem system. As such, emotional signals from limbic structures may be involved in the control of voluntary gait. Indeed, emotional signals may motivate locomotor behavior to approach appetitive stimuli or withdrawal from aversive stimuli. Furthermore, aversive emotional states activating the “flight” response may inhibit the initiation of gait when an individual must approach a threatening stimulus. Alternatively, aversive states activating the “fight” response may facilitate the initiation of gait toward a threatening stimulus. Critically, individuals with Parkinson disease exhibit atypical activation within motor and limbic basal ganglia circuits, causing motor and emotional dysfunction. Thus, particularly during “off” states (off DBS and off DA therapy), PD may be characterized by an impaired link between emotion and motor circuits. As demonstrated in Figure 2-
22, a loss of dopaminergic neurons in the SN should decrease the transfer of information from affective striatal regions to the more dorsal motor striatal regions. Additionally, inhibition of thalamic-cortical projections via increased GABAergic output from the basal ganglia will likely impair the integration of parallel cortico-basal ganglia circuits. Importantly and as discussed in the introduction, standard pharmacological treatments (e.g. levodopa, DA agonists) normalize dopamine levels in individuals with Parkinson disease, alleviating symptoms at all stages of the disease. Thus, the integration of limbic and motor systems via midbrain dopaminergic neurons may be restored in PD patients while “on” medication. Given that pharmacological therapies are limited by their failure to adequately treat postural instability and gait dysfunction, manipulating emotional circuits may be a promising strategy to improve gait initiation and execution in persons with PD.

**Future Research**

Future research should be directed to delineating the degree to which the emotional and motor systems of individuals with PD interact to influence the quality of gait initiation and execution, as well as determine the genetic, biological, neurological, and psychological mechanisms underlying such findings. Furthermore, future work should determine whether pharmacological or surgical interventions influence gait parameters executed under different affective states. These findings would not only lead to a greater understanding of the mechanisms that underpin emotion modulated movement, but may also have important practical implications. Indeed, we (Gamble et al., in review) recently demonstrated that pleasant emotional states facilitate forward gait initiation in healthy individuals. Specifically, exposure to pleasant stimuli improved the quality of the anticipatory postural adjustments during gait initiation and increased
the velocity of the first step. Given that persons with PD exhibit inefficient preparatory postural adjustments and reduced step velocities, manipulation of emotion circuitry holds promise for enhancing gait initiation parameters in individuals with PD while “on” standard anti-Parkinsonian medication. Similar research efforts are necessary to establish whether manipulating emotional state is an efficacious strategy to improve gait initiation in persons with Parkinson disease.

If research documents that the presentation of standardized and empirically established pleasant emotional stimuli facilitate gait initiation in PD, future trials could investigate emotion manipulations of different modalities (i.e., emotionally evocative sounds, imagery based techniques, virtual reality applications). For example, research has recently revealed that common neural representations exist for perceiving emotion in another, feeling an emotion, and imaging an emotion (Jabbi, Bastiaansen, & Keysers, 2008). As such, mental imagery may be a particularly effective route to modify emotion in the clinical setting. Furthermore, future research could investigate how physical therapy sessions/clinical setting can be tailored to induce positive emotional states during gait training to maximize improvements in gait. Additionally, future investigations could examine the clinical utility of long-term gait training in a consistently positive environment or with an approach-oriented strategy.

Significant implications also arise if voluntary movement in PD is not modulated by emotion in the same way as healthy individuals. This finding would suggest an impaired link between emotion and motor circuits in individuals with PD. Affect theorists traditionally agree that the evolutionary purpose of emotion is to facilitate action, motivating behavioral responses to approach pleasant and avoidant unpleasant stimuli.
and situations. Consequently, if emotion information is not being integrated into the motor system in patients with PD, then it is possible that dysfunctional movement in PD is being exacerbated by the failure of emotion to drive or shape final motor behavior, as in healthy individuals. In this case, researchers would need to examine the neural mechanisms underlying the defective emotion and movement link evidenced in PD.

In conclusion, manipulating emotional state to alter motor function may be a promising innovative technique to help those suffering from motor deficits, such as Parkinson disease. With continued empirical effort to understand how emotion modulates movement, researchers may be able to provide valuable recommendations to enhance motor therapy for locomotor dysfunction.
Figure 2-1. A schematic diagram illustrating the changes occurring in the basal ganglia circuitry in Parkinson disease. In the figure on the right, thinner lines from the SNc to the striatum indicate reduced nigrostriatal dopaminergic activity in PD, which ultimately leads to increased inhibitory output of the GPI/SNr (thicker dotted lines) to the thalamus and brainstem, via direct and indirect pathways. Black lines indicate output is excitatory. Dotted lines indicate output is inhibitory. Relative thickness of lines indicates the degrees of activation of the transmitter pathways. D1, D2: Dopamine receptors; GPe: external segment of globus pallidus; GPI: internal segment of globus pallidus; STN: Subthalamic nuclei; SNc substantia nigra pars compacta; SNr: substantia nigra pars reticulate; Glu: glutamate; DA: dopamine. Adapted from Sohn, Y.H. & Hallet, M. (2005). Basal ganglia, motor control and Parkinsonism. In N. Galvez-Jimenez (Ed), Scientific basis for the treatment of Parkinson Disease (2nd ed.). New York: Taylor & Francis.

Figure 2-4. The control of human action production. Adapted from Glover, S. (2004). Separate visual representations in the planning and control of action. Behavioral and Brain Sciences, 27, 3-78.

Figure 2-6. Overhead view of the COP trajectory during forward GI when stepping with the right foot. The COP trace can be divided into 3 sections (S1, S2, and S3) based on the identification of two landmarks. Adapted from Hass et al. (2004). The influence of Tai Chi training on the center of pressure trajectory during gait initiation in older adults. Arch Phys Med Rehabil, 85, 2172-2176

Figure 2-7. The volitional and automatic control of locomotor movements. Dotted lines indicate output is inhibitory. Black lines indicate output is excitatory. Adapted from Takakusaki, Saitoh, Harada, & Kashiwayanagi. (2004). Role of the Basal ganglia-brainstem pathways in the control of motor behaviors. Neuroscience Research, 50, 137-151.
Figure 2-8. Basal Ganglia – thalamocortical control of gait. Dotted lines indicate that output is inhibitory. Black and grey lines indicate output is excitatory. Motor cortical neurons receiving BG output via the thalamus control the volitional aspects of gait. SMA projections to the PMRF regulate the APAs during GI, while M1 projections to the brain stem and spinal cord regulate step execution and postural muscle tone. Adapted from Takakusaki, Saitoh, Harada, & Kashiwayanagi. (2004). Role of the Basal ganglia-brainstem pathways in the control of motor behaviors. Neuroscience Research, 50, 137-151.
Figure 2-9. Basal Ganglia – Brain stem control of gait. Dotted lines indicate that output is inhibitory. Black lines indicate output is excitatory. A GABAergic projection from the SNr to the MLR controls locomotion through connections with the CPGs in the spinal cord. A GABAergic projection from the SNr to the PPN controls postural muscle tone via the muscle tone inhibitory system. Adapted from Takakusaki et al. (2003). Basal ganglia efferents to the brainstem centers controlling postural muscle tone and locomotion: A new concept for understanding motor disorders in basal ganglia dysfunction. Neuroscience, 119, (2003). 293-308.

Figure 2-10. COP displacements in the anterior/ posterior and medial/ lateral directions during forward gait initiation. PD participants exhibit reduced COP displacements relative to the young, elderly. Reprinted from Halliday, Winter, Frank, Patla, & Prince. (1998). The initiation of gait in young, elderly, and Parkinson Disease subjects, Gait and Posture, 8, 8-14.
Figure 2-11. Hypothetical model for the control of gait by the basal ganglia. A. Normal basal ganglia control of voluntary movements, locomotion, and muscle tone. GABAergic basal ganglia projections (in black) to the thalamocortical neurons are involved in volitional control of locomotion, while those to the MLR and PPN are responsible for the automatic control processes of locomotor movements and postural muscle tone. B. Disturbances in the basal ganglia-thalamocortical loop and basal ganglia-brainstem system in PD. Reduced dopaminergic influence on the basal ganglia increases the GABAergic inhibitory outputs of the basal ganglia to the 1) thalamus reducing activation of the motor cortices and 2) the PPN and MLR in the brain stem. Reprinted from Takakusaki, K., Tomita, N., and Yano, M. (2008). Substrates for normal gait and pathophysiology of gait disturbances with respect to the basal ganglia dysfunction. Journal of Neurology, 255, 19-29.

Figure 2-13. A schematic illustration of the defensive cascade model for the electrodermal, startle, and cardiac response systems. The intensity of defensive activation corresponds to the stages of pre-encounter, post-encounter, and overt action, as defined by theories of animal behavior. Adapted from Bradely et al. (2001). Emotion and Motivation I: Defensive and appetitive reactions in picture processing. *Emotion, 1*, 276-298.
Figure 2-14. Inputs and outputs to amygdala nuclei. Itc = intercalated cells; NE = norepinephrine; DA = dopamine; Ach = acetylcholine; 5HT=serotonin; NS = nervous system. Adapted from LeDoux, J. (2007). The amygdala. Current Biology, 17, R868-874.

Figure 2-15. Basal ganglia-thalamocortical limbic circuit. Dotted arrows indicate output is inhibitory. Black arrows indicate output is excitatory. Adapted from Haegelen, Rouaud, Darnault, & Morandi. (2009). The subthalamic nucleus is a key structure of limbic basal ganglia function. Medical Hypothesis, 72, 421-426.
Figure 2-16. New organization of limbic circuit. Glutamatergic excitatory projections are + thin black arrows; Dopaminergic excitatory projections are + thick black arrows; GABAergic inhibitory projections are – dotted arrows. Adapted from Haegelen, Rouaud, Darnault, & Morandi. (2009). The subthalamic nucleus is a key structure of limbic basal ganglia function. *Medical Hypothesis, 72*, 421-426.
Figure 2-17. Summary of thalamic terminal organization in cortical layers. Projections to layer V (A) reinforce corticothalamic and corticostriatal inputs to specific cortico-BG circuits and (B) interface with other cortico-BG circuits via a non-reciprocal projection to a thalamic region part of another circuit system. Projections to layer I interact with dendrites of layer V, further reinforcing each parallel circuit and influence adjacent circuits via corticocortical projections from layer III. Adapted from McFarland & Haber, (2002). Thalamic relay nuclei of the basal ganglia form both reciprocal and nonreciprocal cortical connections, linking multiple frontal cortical areas. *Journal of Neuroscience, 22,* 8117-8132.
Figure 2-18. Proposed schema of information flow between thalamic relay nuclei and frontal cortical areas. Thalamic areas central MD, VA, and VLo are depicted on the left and the corresponding prefrontal, premotor and motor cortical areas on the right. Black lines between cortical regions demonstrate the diverse corticocortical interconnections between adjacent frontal cortical areas. Colored gradients in boxes indicate the functional association between particular thalamic and frontal cortical areas (from most limbic, red, to motor, blue). Arrows illustrate the major thalamocortical and corticothalamic connections between areas. Information is transmitted in a feedfoward manner through strong reciprocal thalamocortical-thalamic connections and prominent nonreciprocal corticothalamic inputs from more rostral, cognitive, or limbic association areas. Adapted from McFarland & Haber, (2002). Thalamic relay nuclei of the basal ganglia form both reciprocal and nonreciprocal cortical connections, linking multiple frontal cortical areas. *Journal of Neuroscience, 22*, 8117-8132.
Figure 2-19. Diagram of the 3 SNS components for each striatal region illustrating an overlapping system in the midbrain. Each striatal region (i.e., shell, core, central, & dorsolateral) has three midbrain components, represented by three ovals. See the text for more explanation. Adapted from Haber, Fudge, & McFarland, (2000). Striatonigostriatal pathways in primates form ascending spiral from the shell to the dorsolateral striatum. *Journal of Neuroscience, 20,* 2369-2382.
Figure 2-20. Diagram of the organization of SNS projections. The colored gradient in rostral and caudal schematics of the striatum illustrates the organization of functional corticostriatal inputs (red = limbic, green = associative, blue = motor). See text for explanation of the spiraling projections, allowing the ventral striatum regions to influence the more dorsal striatal regions. The magnified oval region shows a hypothetical model of the synaptic interactions of SNS projections in reciprocal versus feedforward loops. The reciprocal component (red arrows) of each limb of the SNS projection terminated directly (a) on a DA cell, resulting in inhibition. The nonreciprocal component (orange arrow) terminated indirectly (b) on a DA cell via GABAergic interneuron (brown cell), resulting in disinhibition and facilitation of DA cell burst firing. S = shell. Adapted from Haber, Fudge, & McFarland, (2000). Striato-nigrostriatal pathways in primates form ascending spiral from the shell to the dorsolateral striatum. Journal of Neuroscience, 20, 2369-2382.
Figure. 2-21. A schematic diagram illustrating the integration of limbic information into the basal ganglia systems regulating locomotion in healthy individuals and potentially PD patients while on standard antiparkinsonian medication. Limbic input is integrated into 1) the basal ganglia thalamocortical loop via the thalamic-cortico-thalamic pathway & SNS pathway and 2) the basal ganglia brainstem system via the SNS pathway.
Figure. 2-22. A schematic diagram illustrating 1) the changes associated with PD in the basal ganglia circuitry regulating locomotion and 2) the reduced integration of limbic input into motor basal ganglia circuits in PD. Black lines indicate output is excitatory. Dotted lines indicate output is inhibitory. Relative thickness of lines indicates the degree of activation of transmitter pathways. Red boxes and lines indicate limbic circuitry.
Participants

Participants included 26 patients with idiopathic PD and 26 age matched controls. A power analysis was conducted using data from a previous emotion and gait study in healthy individuals (Gamble et al., in review). This prior research has demonstrated moderate to large effect sizes for the measures of interest [lowest effect sizes (r) for comparisons of pleasant and unpleasant conditions for: reaction time = .436; COP movements = .283; velocity of first step = .350]. Thus, a total sample of 50 (25 per group) permitted identification of significant differences with power = .80 at a critical alpha level of $p < .05$. Patients with PD were recruited through the University of Florida’s Movement Disorder Center and local neurology offices, and from physical and occupational therapy practices in the Gainesville, FL, community. The control participants were recruited from the same community and were age and gender matched to the PD patients. All participants reported no lower extremity injuries that would affect movement, neurological disorders (other than PD for the Parkinson group), major psychiatric disturbances, or medications affecting balance or alertness/attention. All participants were fully informed of the nature of the study and their right to decline participation or withdraw from participation at any point of time. Written informed consent for participation was obtained according to University and Federal guidelines.

Inclusion/Exclusion Criteria for Parkinson Group.

Participants had to have a clinical diagnosis of idiopathic PD (Hughes, Ben-Shlomo, Daniel, & Lees, 1992; Hughes, Daniel, Kilford, & Lees, 1992). The diagnosis was based on the presence of at least two of three cardinal motor signs of PD (i.e.,
akinesia, bradykinesia, resting tremor, and rigidity), with at least one of these signs being resting tremor or bradykinesia. Further inclusion criteria included: 1) complaints of persistent gait disturbance despite optimal medical therapy (score ≥ 1 on item 29 on the motor portion of the UPDRS), 2) a modified Hoehn and Yahr stage between 2.0 and 4.0 in the “off” state, which was obtained within a year of the experimental session; 3) age of 55-80 years; and 4) a stable regimen of anti-Parkinsonian and psychotropic drug therapy for 30 days prior to participation in the study. Exclusion criteria included atypical Parkinsonian features, peripheral neuropathy, vestibular dysfunction, medications affecting balance or alertness/attention, and patients who are “on” freezers (score ≥ 1 on item 14 on the motor portion of the UPDRS). The presence and severity of freezing of gait was also assessed with the New Freezing of Gait Questionnaire (NFOG-Q; Nieuwboer, Rochester, Herman, Vandenberghhe, Emil, Thomaes, & Giladi, 2009). A score of ≥ 1 on item three indicates the presence of FOG. The total score ranges from 0 to 24, with higher scores corresponding to more severe FOG.

Exclusion Criteria for All Participants

Exclusion criteria for all participants included 1) neurological disturbance (other than Parkinson disease for the PD group) or chronic medical illness (i.e., renal, HW, metastatic cancer, etc.); 2) history of major psychiatric disorder (i.e., schizophrenia, bipolar disorder, substance abuse); 3) peripheral neuropathy, orthopedic, vestibular, assisted devices; 4) history of head injury, epilepsy, stroke, or learning disability; 5) dementia. Dementia was screened using the Montreal Cognitive Assessment (MOCA: Nasreddine, Phillips, Bedirian, et al., 2005). Participants with a MOCA score < 26/30 were excluded from the study. Depression symptom severity was screened with the Beck Depression Inventory II (BDI-2: Beck, Steer, & Brown, 1996). Participants scoring
above 19 on the BDI-II (i.e., the cut-off for moderate/severe depressive symptoms) were excluded. Additionally, participants exhibiting high levels of trait anxiety as evidence by a score greater than 45 on the Trait scale of the State Trait Anxiety Inventory (STAI: Spielberger, 1983) were excluded from the study.

**Instrumentation**

**Emotion Manipulation**

Picture viewing was used to induce emotional states during experimental trials. Presented stimuli included 30 digitized photographs selected from the International Affective Picture System (IAPS: Lang, Bradley, & Cuthbert, 2001) representing six affective categories: 1) erotica, 2) happy people, 3) mutilation, 4) contamination, 5) attack, and 6) neutral. All pictures were chosen according to affective norms (NIMH, CSEA, 2005). Threat (i.e., pointed guns, knife attacks), mutilation (i.e., mutilated bodies and faces), and erotica (i.e., erotic couples) stimuli are rated high in arousal and strongly activate defensive and appetitive systems (Bradley, Codispoti, Sabatinelli, & Lang, 2001; Bradley, Codispoti, Cuthbert, & Lang, 2001), respectively. Erotic and threat pictures were included because they have been previously shown to alter gait parameters in healthy individuals (Gamble et al., in review). While the effect of mutilations on gait in healthy individuals has not been evaluated, this category was included because of research showing a mutilation specific hyporeactivity in PD (Miller et al., 2009). The happy people category (i.e., babies, children, happy couples) was

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1. IAPS Pictures: Attack: 6210, 6250, 6260, 6370, 6510; Mutilation: 3060, 3071, 3100, 3150, 3130; Contamination: 9300, 7359, 9301, 7380, 9320; Erotica: 4607, 4670, 4694, 4608, 4676; Pleasants: 4598, 2071, 4623, 2345, 2058; Neutral: 2190, 2200, 2210, 2104, 2305.
included because, similar to the more arousing erotic category, it has been shown to facilitate gait initiation in healthy individuals (Gamble et al., in review). The contamination category (i.e., dirty toilets, bugs on food) provides an unpleasant category which matches the arousal level of the pleasant category and induces clear avoidance motivation. The neutral pictures (i.e., neutral faces) are less arousing than all affective categories. Five blank trials were also included, in which no image (a blank black screen) was presented.

Pictures were projected onto a 3.3 m x 2 m screen using NEC VT 670 digital projector. The screen was located 6 m in front of participants. Pictures were 127 cm x 91 cm and 1024 x 768 pixels. Stimulus presentation and order was randomized and counterbalanced across participants. A custom LabVIEW program (LabVIEW 8.1; National Instruments, Austin, TX) was used to control trial onset, trial offset, and visual stimulus presentation. A computerized 9-point version of the self-assessment manikin (SAM: Lang, 1980) was used to obtain subjective ratings of valence and arousal at the conclusion of gait testing.

**Task**

Participants were fitted with retro-reflective markers which were placed bilaterally on the lower body at the following locations: anterior superior iliac, posterior superior iliac, lateral epicondyle of the knee, lower lateral 1/3 surface of the thigh, lateral malleolus, tibia, second metatarsal head, and calcaneus. Once the reflective markers were in place, each participant was given the opportunity to walk around the testing environment to become accustomed to the instrumentation.

During the gait initiation trials participants stood with their feet in a self-selected stance width, with both feet on one force platform (Bertec, Columbus, Ohio model
The positioning of the feet was recorded to allow for standardization for all future trials. In response to picture offset, participants began walking and continued for several steps (approximately 4 m). Participants walked at picture offset rather than onset to avoid possible attentional effects on performance resulting from viewing the picture and simultaneously initiating gait. Additionally, this approach replicates previous work examining the influence of emotional state on gait initiation in healthy individuals (Gamble et al., in review).

The kinematic characteristics of the locomotor tasks were sampled at a rate of 120 Hz using a ten-camera Optical Motion Capture system (Vicon Peak, Oxford, UK). The motion capture system collected three-dimensional coordinate data from retro-reflective markers. Ground reaction forces (GRF) and COP measurements were collected at 1200 Hz using three Bertec force platforms (Bertec, Newton, MA; size 60 x 40 cm) mounted flush with the laboratory floor.

**Procedure**

Participants with PD performed the proposed tasks while “on” their normal dosage of dopaminergic medication. Participants were also instructed to wear any eyeglasses or contacts that they typically wear so that poor visual acuity would not interfere with picture viewing during the experimental tasks. Upon arrival to the laboratory, participants signed a written informed consent approved by the University’s Institutional Review Board and all questions were answered. Participants also completed a battery of self-report questionnaires including: demographics, the state and trait forms of the STAI (Spielberger, 1983), the state version of the Positive and Negative Affect Schedule (PANAS: Watson, Clarke, & Tellegen, 1988), the BDI-2 (Beck et al., 1996), the Apathy
Scale (Starkstein, Migliorelli, Manes, Teson, Petracca, Chemerinski et al., 1995), and the NFOG-Q (Nieuboor et al., 2009). The experimenter then administered the MOCA.

Following completion of questionnaires, the following measurements were obtained: height, weight, leg length, knee width, and ankle width. Participants were fitted with retro-reflective markers and familiarized with the protocol, completing three practice trials using unique neutral pictures and one blank picture. The practice trials were immediately followed by 35 data collection trials. Participants were informed that each trial begins with the presentation of a fixation cross on the video screen (2 s), which would be replaced by a picture for 2-4 s. Participants were instructed to look at the picture the entire time it was on the screen. At picture offset, the screen became blank (white). Participants were instructed to initiate walking with their preferred limb immediately as possible following picture offset and to continue walking for several steps at their self-selected pace. Each participant performed 5 trials for each affective category and 5 trials using the blank black screen, for a total of 35 trials. To determine if participants became physically fatigued during the experimental session, participants also completed five self-initiated trials with no picture presentation before (pre-trials) and after (post-trials) the experimental trials. Following completion of the gait initiation trials, participants completed the computerized SAM scale to provide an arousal and valence rating (scale: 1-9) for each picture previously viewed.

Data Reduction

Reaction time, displacement and velocity of COP in a given direction, step length, average step velocity, and instantaneous velocity of the first and second steps were calculated.
**Reaction time (RT).** Reaction time was operationalized as the latency from the movement trigger (picture offset) to the initiation of the motor response. Initiation of motor response was defined as the time at which the vertical differentiation between the swing limb and stance limb reaches a 5% threshold of force production (Diermayr, Gynsin, Hass, & Gordon, 2008).

**COP Displacement and Velocity.** Movement of the COP trajectory was quantified by the displacements and velocities of the COP trace observed over time in both the medio-lateral (MP) and anterior-posterior (AP) direction. The COP trace during the gait initiation trials was divided into three periods (S1: anticipatory postural adjustment; S2: weight transfer; S3: locomotor) by identifying two landmark events (Hass et al., 2004) (See Figure 3-1).

![Figure 3-1](image-url)  

**Figure 3-1.** Overhead view of the path of the COP during forward GI when stepping with the right foot. Adapted from Hass, C.J. Gregor, R.J., Waddell, D.E., Oliver, A., Smith, D.W., Fleming, R.P. et al. (2004). The influence of Tai Chi training on the center of pressure trajectory during gait initiation in older adults. *Arch Phys Med Rehabil, 85* (10), 1593-1598.

S1 begins with picture offset and ends with COP located in its most posterior and lateral position toward the initial swing limb (Landmark 1). S2 is defined as the translation of
the COP toward the stance limb ending at landmark 2, which is the position under the stance limb on which the COP begins to move forward under the foot. S3 begins at landmark 2 until toe off of the initial stance limb as the COP is translated anteriorly. During these three periods, the following dependent variables were evaluated: 1) displacement of the COP in the x (AP) and y (ML) direction, and 2) the average velocity of the COP in the x and y direction.

**Step length and velocity.** The gait cycle was time normalized from the instance of heel strike to the next heel strike of the same leg. Step length of the first step was calculated as the displacement in centimeters (cm) of the initial swing limb heel marker from its initial resting position until heel strike. Step length of the second step was calculated as the displacement in centimeters from the heel position of the swing leg at first heel strike to the heel position of the stance leg at heel strike. An average velocity of the swing leg was calculated for each step as the step length divided by the corresponding change in time in centimeters per second (cm/s). The instantaneous velocity of the first and second steps was also calculated using the central difference method: \( v(t) = \frac{v(t_{i+1}) - v(t_{i-1})}{2\Delta t}. \)

**Percent change scores.** Replicating previous research, we created a single index for each movement variable that represented the change in movement due to each affective category relative to the neutral category. Because PD patients exhibited smaller and slower COP adjustments and steps compared to the control participants, percent change scores rather than raw bias scores were used to remove the influence of baseline differences. Percent change scores were calculated with the following formula: \([\text{emotional category/neutral category} \times 100] - 100. \) A positive score therefore
indicates greater values for the dependent variable during the emotional category relative to the neutral category, while a negative score indicates reduced values for the dependent variable during the emotional category relative to the neutral category. The actual values for each gait measure as well as the percent change scores were the basis for statistical analyses.

**Statistical Analyses**

Descriptive characteristics were calculated for each group for age, height, weight, and all affective state and trait measures. Independent samples t-tests were used to determine whether the PD and control groups differed on any of the descriptive characteristics. Additionally, to determine whether fatigue may have influenced the gait initiation trials as the experimental session progressed, the COP variables and the step variables for the pre- and post-trials were each analyzed with a 2 (GROUP: PD, control) × 2 (Time: pre, post) MANOVA with repeated measures on the second factor.

**Primary Statistical Analyses**

To determine whether affective category and the presence of PD altered the speed at which gait was initiated, RT was analyzed in a 2 (GROUP: PD, control) × 7 (CATEGORY: erotica, happy people, mutilation, contamination, attack, neutral, blank) analysis of variance (ANOVA) with repeated measures on the second factor. To establish whether the degree of change in RT due to each affective category compared to the neutral category differed between the PD and control groups, RT percent change scores were analyzed with a 2 (GROUP: PD, control) × 5 (CATEGORY: erotica, happy people, mutilation, contamination, attack) ANOVA with repeated measures on the second factor. The CATEGORY factor for all analyses involving the percent change scores had only five levels because these analyses were only concerned with
evaluating the change in movement following the five affective categories relative to the neutral category.

COP displacement and velocity values and percent change scores were evaluated during the 3 periods of the COP trace (S1, S2, S3). Thus, 3 separate 2 (GROUP: PD, control) × 7 (CATEGORY: erotica, happy people, mutilation, contamination, attack, neutral, blank) multivariate analyses of variance (MANOVA) with repeated measures on the second factor was conducted to determine whether affective category and the presence of PD alters the COP trajectory, while controlling for type I error. The percent change scores for the COP dependent variables were also analyzed in 3 separate 2 (GROUP: PD, control) × 5 (CATEGORY: erotica, happy people, mutilation, contamination, attack) MANOVAs with repeated measures on the last factor. The dependent variables for each MANOVA included AP and ML displacement and AP and ML velocity.

Step length and velocity of the first and second steps and stride length were analyzed in a 2 (GROUP: PD, control) × 7 (CATEGORY: erotica, happy people, mutilation, contamination, attack, neutral, blank) MANOVA with repeated measures on the second factor. To determine whether differences existed between the PD and control groups in the degree of change observed in the step execution parameters due to each affective category relative to the neutral, percent change scores for step length and velocity of the first and second steps and stride length were analyzed in a 2 (GROUP: PD, control) × 5 (CATEGORY: erotica, happy people, mutilation, contamination, attack) MANOVA with repeated measures on the second factor.
For each MANOVA, separate two-way ANOVAs were performed for follow-up testing when appropriate. We also conducted two-way ANOVAs (Group × Category) on the SAM valence and arousal ratings. For the ANOVAs for RT and SAM data, if the sphericity assumption was violated, then Greenhouse-Geisser degrees of freedom corrections were applied to obtain the critical $p$-value. Follow-up analyses were conducted using Tukey HSD procedure and simple effects tests for significant main effects and interactions, respectively. For all analyses, the critical probability value was set at $p < .05$.

**Secondary Statistical Analyses**

Even though the PD and control group were selected to be as homogenous as possible on dispositional variables (i.e., mood variables and disease severity), we acknowledge that some degree of heterogeneity characterized our sample. Additionally, analyses showed that the PD group differed from the control group on the dispositional variables of depression, apathy, and height. Our study design produced a multilevel data set in which gait initiation outcomes varied both between trials and between participants. Thus we used hierarchical linear modeling (HLM) and HLM 6.6 (Raudenbush & Bryk, 2002) to examine 1) the effect of self reported valence and self-reported arousal on gait initiation parameters, 2) the effect of depression, apathy, and PD on gait initiation parameters, while controlling for height, and 3) the moderating effect of depression, apathy, and PD on level-1 effects (i.e., the effect of valence/arousal on movement parameters), while controlling for height.

The data were nested in a “person-trial,” nesting the level-1 gait initiation outcome variables in the level-2 person variable. The focus of the analyses was on how the emotion induction, measured by the valence and arousal ratings, influenced the gait
initiation parameters. Thus, we included only the data from the trials in which an IAPS image was presented (i.e., 30 trials per person). Level-1 predictors included two continuous variables: 1) SAM valence ratings (Valence), and 2) SAM arousal ratings (Arousal). Level-2 predictors included three continuous variables and one dichotomous variable, respectively: 1) level of depression (BDI score), 2) level of apathy (Apathy Scale score), 3), height (HT), and 4) PD (Control = 0; PD = 1). The level-1 independent variables were group-mean centered and the level-2 variables were grand-mean centered. An initial analyses was conducted on the PD group with disease severity (UPDRS score) as a level-2 variable. These analyses showed that disease severity was not a significant predictor of any of the gait initiation parameters, therefore the PD and control groups were combined for the all of the HLM analyses and PD was included as a level-2 variable.

Per recommendations of Raudenbush and Bryk (2002), four distinct hierarchical linear models for each dependent variable assessing gait initiation were tested. First, a Random ANOVA model tested whether significant variation existed in the dependent variables between participants. Second, a Means as Outcomes (MAO) model determined whether between person variation in the dependent variables was predicted by depression, apathy, or PD, after controlling for height. Third, a random regression coefficient model was conducted to test whether self-reported measures of arousal and valence predicted between trial variation in the dependent variables. Fourth, an intercepts and slopes as outcomes (IASO) model tested whether depression, apathy, or PD predicted between trial (i.e., arousal, valence) effects. The level-1 and level-2 models for the IASO analyses were:
Level 1: \( G_{ij} = \pi_{0j} + \pi_{1j} \text{(Valence)} + \pi_{2j} \text{(Arousal)} + e_{ij} \)

Level 2: 
\[
\pi_{0j} = \beta_{00} + \beta_{01}(BDI) + \beta_{02}(Apathy) + \beta_{03}(PD) + \beta_{04}(HT) + r_{0j} \\
\pi_{1j} = \beta_{10} + \beta_{11}(BDI) + \beta_{12}(Apathy) + \beta_{13}(PD) + \beta_{14}(HT) + r_{1j} \\
\pi_{2j} = \beta_{20} + \beta_{21}(BDI) + \beta_{22}(Apathy) + \beta_{23}(PD) + \beta_{24}(HT) + r_{2j}
\]
CHAPTER 4
RESULTS

Participants

Twenty-six individuals with idiopathic PD (female = 3) and twenty-five aged-matched controls (females = 3) participated in this study. Three male PD patients were excluded from statistical analyses: two patients scored above 19 on the BDI and one patient scored below 26 on the MOCA. Thus, after the removal of these participants the PD group included 23 individuals. A summary of demographic, affective state and trait, and clinical characteristics are presented in Table 1. As shown, the PD and control groups did not differ statistically with respect to age, mass, cognitive dysfunction, trait anxiety, and positive and negative affect. PD patients obtained significantly higher scores than controls on the BDI-2, Apathy Scale, and state version of the STAI. However, both groups had mean BDI scores in the non-depressed range and mean STAI-S scores indicating a low to moderate level of state anxiety. All participants reported being free of neurological disorders (other than PD for the Parkinson group), major psychiatric disturbances, and medications affecting balance or alertness/attention. The PD patients were in the middle stages of their disease (Hoehn and Yahr stage of 2 or 3) and demonstrated a moderate degree of disease severity based on the UPDRS (Fahn, Elton, & Committee, 1987). These staging and severity indices were obtained within six months of participation in the current study.

Data points 3 SDs from the mean were considered extreme scores and were removed prior to analysis. Additionally, trials in which participants did not initiate gait following picture offset (i.e., did not initiate gait at all or initiated gait prior to picture offset) were removed. Participants missing one or more scores were completely
removed from each separate analysis. Consequently, 2 PD participants and 2 control participants were removed from the COP analyses and the step length/velocity analyses, and 2 PD participants and 1 control participant were removed from the RT analyses. Technical problems also led to the exclusion of reaction time data from 3 participants.

Table 4-1 Demographic, affective, and clinical characteristics by group.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>PD (n=23)</th>
<th>Control (n=25)</th>
<th>Statistical test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>70.13 (7.63)</td>
<td>67.20 (4.97)</td>
<td>t(46) = 1.56, p = .13</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>76.92 (9.46)</td>
<td>80.65 (14.91)</td>
<td>t(46) = -1.03, p = .31</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>168.09 (4.72)</td>
<td>172.21 (6.86)</td>
<td>t(46) = -2.41, p = .02*</td>
</tr>
<tr>
<td>Trait Anxiety (STAI-T)</td>
<td>32.13 (7.70)</td>
<td>29.40 (6.14)</td>
<td>t(46) = 1.36, p = .18</td>
</tr>
<tr>
<td>Depression (BDI-2)</td>
<td>7.91 (4.86)</td>
<td>4.72 (3.05)</td>
<td>t(46) = 2.70, p = .01*</td>
</tr>
<tr>
<td>Apathy (Apathy Scale)</td>
<td>13.17 (6.58)</td>
<td>8.16 (3.00)</td>
<td>t(46) = 3.35, p &lt; .01*</td>
</tr>
<tr>
<td>State Anxiety (STAI-S)</td>
<td>32.22 (9.42)</td>
<td>26.64 (6.61)</td>
<td>t(46) = 2.36, p = .02*</td>
</tr>
<tr>
<td>PANAS Positive scale</td>
<td>33.91 (7.37)</td>
<td>37.48 (5.06)</td>
<td>t(46) = -1.96, p = .06</td>
</tr>
<tr>
<td>PANAS Negative scale</td>
<td>12.95 (3.93)</td>
<td>11.16 (2.38)</td>
<td>t(46) = 1.91, p = .06</td>
</tr>
<tr>
<td>Cognitive Dysfunction (MOCA)</td>
<td>27.74 (1.45)</td>
<td>27.72 (1.02)</td>
<td>t(46) = 0.52, p = .96</td>
</tr>
<tr>
<td>Hoehn and Yahr stage</td>
<td>2.95 (0.50)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>UPDRS Motor</td>
<td>26.74 (6.18)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note. * = significant. UPDRS Motor: motor scale of the Unified Parkinson Disease Rating Scale.

Primary Statistical Results

Reaction Time

*Raw RT scores.* The 2-way ANOVA revealed a significant main effect of Group \([F(1, 38) = 4.83, p = .034, \eta^2 = .113]\) and Category \([F(3.63, 137.95) = 3.24, p = .017, \eta^2 = .08]\). The control group \((M = 331 \text{ ms}, SD = 21)\) exhibited faster reaction times on the gait initiation task compared to the PD group \((M = 400 \text{ ms}, SD = 23)\). Across all participants, exposure to the attack pictures speeded reaction times on the GI task compared to all other categories expect for the blank \((attack = 320 \text{ ms} (SD = 104),\)
mutilation = 370 ms \( (SD = 134) \), contamination = 398 ms \( (SD = 160) \), erotic = 383 \( (SD = 149) \), happy people = 369 \( (SD = 135) \), neutral = 344 ms \( (SD = 98) \), blank = 354 \( (SD = 138) \). Additionally, reaction time was slower following exposure to the contamination, mutilation, erotic, and happy people pictures compared to the neutral pictures (See Figure 4-1a). The group by category interaction was not significant \( (p > .05) \).

**RT percent change scores.** The 2-way ANOVA conducted on the reaction time percent change scores similarly showed a significant main effect of category \[ F(2.84, 113.76) = 6.43, \ p = .001, \eta^2 = .14 \], confirming that reaction time was faster following the presentation of the attack pictures compared to all other affective picture categories (See Figure 4-1b). The main effect of group and the group by category interaction were not significant \( (p's > .05) \).

**S1 Region of the COP Trace**

**Raw COP scores.** The MANOVA conducted on the pre- and post-trials showed a significant main effect of time, \( Wilks’ \ Lambda = .612, F(4, 34.00) = 5.38, \ p = .002, \eta^2 = .39 \). The follow-up tests were significant for the AP displacement, \( F(1, 37) = 12.24, \ p = .001, \eta^2 = .25 \) [means: pre = 2.04 cm (.16), post = 2.52 cm (.23)], ML displacement, \( F(1, 37) = 8.20, \ p = .007, \eta^2 = .18 \) [means: pre = -1.70 cm (.25), post = -2.37 cm (.20)], and AP velocity, \( F(1, 37) = 7.01, \ p = .012, \eta^2 = .16 \) [means: pre = 2.58 cm/s (.32), post = 3.38 cm (.41)]. For all participants, the displacement and velocity of the posterior COP movement, as well as the lateral COP displacement in the S1 region significantly increased from the pre-trials to the post-trials, indicating that fatigue was likely not a factor influencing the S1 COP variables during the experimental session. The main effect of group and the group by time interaction were not significant \( (p’s > .05) \).
The 2-way MANOVA conducted on the experimental trials revealed significant main effects of category, *Wilks’ Lambda* = .832, *F*(24, 828.00) = 1.87, *p* = .007, η² = .05 and group, *Wilks’ Lambda* = .619, *F*(4, 37) = 5.70, *p* = .001, η² = .38. Figure 4-2 presents the displacement and velocity of the COP movement in the posterior and lateral directions. The respective follow-up ANOVAs for the main effect of category produced significant effects for the displacement [*F*(6, 240) = 4.30, *p* > .001, η² = .10] and velocity [*F*(4.04, 161.68) = 3.565, *p* = .008, η² = .08] of the COP movement in the AP direction. As hypothesized, exposure to the erotic and happy people pictures resulted in a significant increase in the magnitude of the COP displacement in the posterior direction compared to the attack, mutilation, contamination, and neutral pictures (Figure 4-2a). Similarly, exposure to the erotic pictures compared to the attack, contamination, and neutral (*p* = .077) pictures resulted in greater velocity of the posterior COP movement (Figure 4-2b). Additionally, the posterior COP velocity was 1) greater following exposure to the happy people pictures compared to the contamination pictures and 2) reduced following exposure to the attack, mutilation, contamination, and neutral pictures compared to the blank pictures. The follow-up ANOVAs for the displacement (*p* = .083; Figure 4-2c) and velocity (*p* = .077; Figure 4-2d) of the COP movement in the lateral direction were not significant.

The follow-up ANOVAs for the main effect of group were significant for each COP measure in the S1 phase: posterior displacement, *F*(1, 40) = 21.73, *p* > .001, η² = .35 [means: Control = 4.88 cm (.32), PD = 2.70 cm (.35)]; posterior velocity, *F*(1, 40) = 13.92, *p* = .001, η² = .26 [means: Control = 7.47 cm/s (.64), PD = 3.93 cm/s (.70)]; lateral displacement, *F*(1, 40) = 6.19, *p* = .017, η² = .13 [means: Control = -3.50 cm
lateral velocity, $F(1, 40) = 7.05, p = .011, \eta^2 = .150$ [means: Control = -5.31 cm/s (.41), PD = -3.68 cm/s (.46)]. As expected, these results showed that the magnitude of the displacement and velocity of the COP movement in each direction was greater for the control group compared to the PD group. The group by category interaction was not significant ($p = .165$).

**COP percent change scores.** The 2-way MANOVA on the percent change scores revealed a significant main effect of category for the variables in the S1 region of the COP curve, *Wilks' Lambda* = .823, $F(16, 480.00) = 1.98, p = .013, \eta^2 = .05$. Figure 4-3 presents the percent change scores for displacement and velocity of the COP movement in the posterior and lateral directions. The respective follow-up ANOVAs showed a significant effect of category for the displacement of the COP movement in the posterior direction, $F(2.84, 113.60) = 5.73, p = .001, \eta^2 = .13$. The posterior COP displacement percent change scores for the happy people and erotic pictures were significantly greater than the percent change scores for the attack and contamination pictures (Figure 4-3a). The ANOVA conducted on the velocity of the posterior COP approached significance, $F(2.56, 102.49) = 2.66, p = .06, \eta^2 = .06$, with the erotic and happy people pictures resulting in greater posterior velocity percent change scores compared to the attack and contamination pictures (Figure 4-3b). The ANOVAs also showed a significant effect of category for the COP displacement in the lateral direction, $F(4, 160) = 3.11, p = .017, \eta^2 = .07$. The percent change scores for 1) the erotic pictures were significantly greater than the mutilation pictures and 2) the happy people pictures were significantly greater than the mutilation and contamination pictures (Figure 4-3c). The ANOVA conducted on the lateral COP velocity percent change scores was not
significant ($p = .182$; Figure 4-3d). The main effect of group and the group by category interaction were not significant ($p$’s $> .05$).

**S2 Region of the COP Trace**

*Raw COP scores.* The MANOVA conducted on the pre- and post-trials showed a significant main effect of group, $Wilks' Lambda = .716$, $F(4, 34.00) = 2.67$, $p = .049$, $\eta^2 = .24$ and time, $Wilks' Lambda = .611$, $F(4, 34.00) = 5.41$, $p = .002$, $\eta^2 = .39$. Significant group differences were found for AP displacement, $F(1, 37) = 5.70$, $p = .022$, $\eta^2 = .13$ [means: Control = -0.98 cm (.51), PD = 0.80 cm (.55)], ML displacement, $F(1, 37) = 5.17$, $p = .029$, $\eta^2 = .12$ [means: Control = 11.03 cm (.45), PD = 9.53 cm (.48)], and ML velocity, $F(1, 37) = 4.90$, $p = .033$, $\eta^2 = .12$ [means: Control = 10.91 cm/s (.70), PD = 8.64 cm/s (.75)]. Across all trials the control group exhibited greater displacement and velocity of the medial COP movement in the S2 region compared to the PD group. The follow-up tests for time were significant for the AP displacement, $F(1, 37) = 8.91$, $p = .005$, $\eta^2 = .19$ [means: pre = -.60 cm (.37), post = .42 cm (.45)] and ML velocity, $F(1, 37) = 11.17$, $p = .002$, $\eta^2 = .23$ [means: pre = 9.17 cm/s (.54), post = 10.38 cm/s (.55)]. The velocity of the medial COP movement in the S2 region significantly increased from the pre-trials to the post-trials. The group by time interaction was not significant ($p$’s $> .05$).

The 2-way MANOVA conducted on the experimental trials revealed a significant main effect of group, $Wilks' Lambda = .584$, $F(4, 37) = 6.60$, $p > .001$, $\eta^2 = .416$. The follow-up ANOVAs produced a significant effect of group for the AP COP displacement, $F(1, 40) = 7.60$, $p = .009$, $\eta^2 = .16$ [means: Control = .21 cm (.32), PD = 1.81 cm (.43)]; the ML COP displacement, $F(1, 40) = 9.54$, $p = .004$, $\eta^2 = .19$ [means: Control = 11.87 cm (.45), PD = 9.81cm (.49)]; and the ML COP velocity, $F(1, 40) = 11.49$, $p = .002$, $\eta^2 = .22$ [means: Control = 1.44 cm/s (.08), PD = 1.06 cm/s (.08)]. Across picture categories,
the control group displayed greater displacement and velocity of the medial COP movement in the S2 region compared to the PD group (See Figure 4-4). The main effect of category and the interaction were not significant ($p$’s > .05).

*COP percent changes scores.* The main effect of category approached significance, Wilks’ Lambda = .853, $F(16.00, 480.28) = 1.60, p = .065, \eta^2 = .039$, and was driven by a significant ANOVA for the velocity of the COP trajectory in the ML direction, $F(4, 160) = 3.35, p = .011, \eta^2 = .052$. While such findings must be considered with caution due to the lack of omnibus significance, the data suggest that exposure to 1) erotic and happy people pictures lead to greater ML velocity percent change scores compared to mutilation pictures and 2) happy people pictures resulted in greater ML velocity percent change scores compared to contamination pictures (See Figure 4-5). The main effect of group and the interaction were not significant ($p$’s > .05).

**S3 Region of the COP Trace**

*Raw COP scores.* The MANOVA conducted on the pre- and post-trials showed a significant main effect of time, Wilks’ Lambda = .375, $F(4, 34.00) = 14.17, p < .001, \eta^2 = .63$. The follow-up tests were significant for only the AP displacement, $F(1, 37) = 4.83, p = .034, \eta^2 = .12$ [means: pre = -14.56 cm (.98), post = -13.26 cm (1.12)]. The magnitude of the anterior displacement of the COP movement in the S3 region significantly decreased from the pre-trials to the post-trials. The main effect of group and the group by time interaction were not significant ($p$’s > .05). The MANOVA conducted on the experimental trials showed no significant effects for the S3 portion of the COP trajectory ($p$’s > .05).

*COP percent change scores.* No significant effects were found for the percent change scores during the S3 portion of the COP trajectory ($p$’s > .05).
Average Step Length and Step Velocity of the 1st and 2nd Steps

Raw Step length and velocity scores. The MANOVA conducted on the pre- and post-trials showed a significant main effect of time, Wilks’ Lambda = .430, F(5, 35.00) = 9.30, p < .001, η² = .57. The follow-up tests were significant for the length of step 1, F(1, 39) = 8.86, p = .005, η² = .19 [means: pre = 51.53 cm (1.31), post = 53.85 cm (1.48)], stride length, F(1, 39) = 5.23, p = .028, η² = .12 [means: pre = 105.66 cm (2.33), post = 108.53 cm (2.77)], velocity of step 1, F(1, 39) = 10.00, p = .003, η² = .20 [means: pre = 47.18 cm/s (2.15), post = 53.41 cm/s (2.38)], and velocity of step 2, F(1, 39) = 19.39, p > .001, η² = .19 [means: pre = 80.93 cm/s (2.54), post = 87.45 cm/s (3.07)]. The length and velocity of step 1, stride length, and the velocity of step 2 significantly increased from the pre-trials to the post-trials, indicating that fatigue was not likely a factor influencing the step execution component of GI during the experimental session. The main effect of group and the group by time interaction were not significant (p’s > .05).

The 2-way MANOVA conducted on the experimental trials revealed a significant main effect of group, Wilks’ Lambda = .698, F(5, 38) = 3.29, p = .014, η² = .30. The follow-up tests revealed significant group differences for each dependent variable: length of step 1, F(1, 42) = 16.28, p > .001, η² = .28 [mean: Control = 57.02 cm/s (1.74), PD = 46.90 cm/s (1.82)]; length of step 2, F(1, 42) = 10.22, p = .003, η² = .20 [mean: Control = 58.85 cm/s (1.68), PD = 51.07 cm/s (1.68)]; stride length, F(1, 42) = 14.63, p > .001, η² = .26 [mean: Control = 115.87 cm/s (3.24), PD = 97.92 cm/s (3.39)]; velocity of step 1, F(1, 42) = 14.63, p = .001, η² = .25 [mean: Control = 64.45 cm/s (2.72), PD = 49.66 cm/s (2.84)]; velocity of step 2, F(1, 42) = 5.55, p = .023, η² = .12 [mean: Control = 95.47 cm/s (3.90), PD = 82.16 cm/s (4.09)]. As hypothesized the control group exhibited longer step and stride lengths and greater step velocities
compared to the PD group (See Figure 4-6). The main effect of category and the interaction were not significant ($p$'s > .05).

**Step length and velocity percent change scores.** The 2-way MANOVA conducted on the percent change scores produced a significant category by group interaction, \( \text{Wilks' Lambda} = .825, F(20, 544.88) = 1.62, p = .043, \eta^2 = .047 \). Figure 4-7 presents the percent change scores for length and velocity of the first and second step. The follow-up tests revealed a significant interaction for the velocity of the first step, \( F(4, 168) = 3.49, p = .009, \eta^2 = .08 \). Exposure to mutilation pictures for the PD group resulted in reduced step velocity percent changes scores compared to mutilation and erotic pictures for the control group and happy people pictures for both groups. The group and category main effects were not significant ($p$'s > .05). Additionally, no significant findings were found for step 2.

**Instantaneous Velocity of the 1st and 2nd Steps**

**Raw Instantaneous step velocity scores.** Instantaneous velocity was measured to index the velocity at heel strike of the first and second steps. The MANOVA conducted on the pre- and post-trials showed a significant main effect of group, \( \text{Wilks' Lambda} = .857, F(2, 38.00) = 3.16, p = .05, \eta^2 = .14 \) and time, \( \text{Wilks' Lambda} = .434, F(2, 38.00) = 24.80, p < .001, \eta^2 = .57 \). Significant group differences were found for velocity of step 1, \( F(1, 39) = 6.38, p = .016, \eta^2 = .14 \) [means: Control = 81.25 cm/s (3.64), PD = 68.09 cm/s (3.73)] and step 2, \( F(1, 39) = 3.94, p = .05, \eta^2 = .09 \) [means: Control = 106.14 cm/s (4.02), PD = 94.70 cm/s (4.12)]. Across all trials the control group exhibited greater instantaneous velocity at heel strike for step 1 and 2 compared to the PD group. The follow-up tests for the main effect of time were also significant for the velocity of step 1, \( F(1, 39) = 42.68, p < .001, \eta^2 = .52 \) [means: pre = 71.13 cm/s (2.58), post = 78.21 cm/s.
and the velocity of step 2, $F(1, 39) = 18.72, p < .001, \eta^2 = .32$ [means: pre = 97.41 cm/s (2.77), post = 103.43 cm/s (3.14)]. Similar to the average step velocity results, the instantaneous velocity of step 1 and 2 significantly increased from the pre-trials to the post-trials. The group by time interaction was not significant ($p > .05$).

The MANOVA conducted on the instantaneous velocity of the first and second steps for the experimental trials revealed a significant main of effect of group, Wilks’ $Lambda = .862, F(3.27, 41.00) = 3.27, p = .048, \eta^2 = .14$. The follow-up tests revealed significant group differences for velocity of step 1, $F(1, 42) = 6.70, p = .013, \eta^2 = .14$ [mean: Control = 83.10 cm/s (3.65), PD = 69.44 cm/s (3.82)] and velocity of step 2, $F(1, 42) = 4.64, p = .037, \eta^2 = .10$ [mean: Control = 127.77 cm/s (4.19), PD = 99.70 cm/s (43.89)]. The control group exhibited greater instantaneous velocity for step 1 and 2 compared to the PD group. The main effect of category and the group by category interaction were not significant ($p$’s > .05).

*Instantaneous step velocity percent change scores.* The MANOVA conducted on the instantaneous step velocity percent change scores revealed no significant effects ($p$’s > .05).

**SAM Ratings**

The 2-way ANOVA conducted on the valence ratings revealed a significant main effect of category, $F(2.97, 121.70) = 305.85, p > .001, \eta^2 = .882$. As expected all participants rated the erotic and happy people pictures as significantly more pleasant than the mutilation, attack, contamination, and neutral pictures (Figure 4-8a). The mutilation pictures were rated significantly more unpleasant than all other picture categories, and the attack and contamination pictures were rated as more unpleasant.
than the neutral pictures. The main effect of group and the interaction were not significant ($p's > .05$).

The 2-way ANOVA conducted on the arousal ratings also demonstrated a significant main effect of category, $F(2.96, 121.29) = 41.81, p > .001$, $\eta^2 = .51$. As demonstrated in Figure 4-8b, the erotic pictures were rated significantly more arousing than all other picture categories and mutilation pictures were rated more arousing than all categories except for erotic. Attack pictures were rated significantly more arousing than the happy people, contamination, and neutral pictures. Finally, the contamination and happy people pictures were rated significantly more arousing than neutral pictures. The main effect of group and the interaction were not significant ($p's > .05$).

**Secondary Statistical Results**

**Reaction Time**

The RA model indicated that significant variation existed among individuals’ reaction time on the gait initiation task ($p < .001$). However, the MAO model revealed that the variation in reaction time was not significantly predicted by any of the level-2 variables ($p's > .05$). The RRC model also showed that no significant relationship existed between self-reported valence/arousal and reaction time ($p's > .05$). This analysis also revealed that the relationship between the level-1 variables and reaction time did not vary significantly between participants ($p's > .05$); thus the data were not analyzed with an IASO model.

**S1 Region of the COP Trace**

The RA model indicated significant variation existed among individuals in their posterior and lateral displacement and velocity of the COP movements in the S1 region on the gait initiation task ($p's < .001$). The MAO model showed that the presence of PD
significantly predicted the posterior displacement, $\pi_{03} = -1.70$, $SE = 0.55$; $t(40) = -3.08$, $p = 0.004$, and posterior velocity of the COP movement, $\pi_{03} = -0.025$, $SE = 0.116$; $t(40) = -2.17$, $p = 0.036$. Confirming the MANOVA results, individuals with PD exhibited reduced COP displacement and velocity in the posterior direction compared to healthy control individuals, even after controlling for height. The RRC models showed that each COP variable in the S1 region had a significant relationship with self-reported valence, AP displacement $\pi_{10} = 0.036$, $SE = 0.009$; $t(1240) = 4.09$, $p < 0.001$; AP velocity $\pi_{10} = 0.007$, $SE = 0.003$; $t(44) = 2.36$, $p = 0.023$; ML displacement $\pi_{10} = 0.021$, $SE = 0.008$; $t(1241) = -2.53$, $p = 0.019$; ML velocity $\pi_{10} = 0.005$, $SE = 0.002$; $t(1241) = -2.70$, $p = 0.008$. Supporting the MANOVA results, exposure to pictures which were rated more pleasant, relative to unpleasant, resulted in greater magnitude of the COP displacement and velocity in the posterior and lateral directions. The RRC models also revealed that the level-1 slope for arousal and ML COP displacement ($p = .049$) and the slope for valence and AP COP velocity ($p = .015$) significantly varied between participants. However, the IASO models indicated that no level-2 variables predicted the relationship between arousal and ML COP displacement or valence and AP COP velocity ($p$’s > .05).

**S2 Region of the COP Trace**

The RA model indicated significant variation existed among individuals in their AP and ML displacement and velocity of the COP movements in the S2 region on the gait initiation task ($p$’s < .001). The MAO model showed that participants’ height significantly predicted the medial COP displacement, $\pi_{04} = 0.117$, $SE = 0.041$; $t(40) = 2.86$, $p = 0.007$. As expected, participants who were taller demonstrated greater medial COP displacement in the S2 region. The presence of PD significantly predicted the
medial COP velocity, $\pi_{04} = -0.299$, $SE = 0.140$; $t(40) = -2.13$, $p = 0.039$. Individuals with PD were more likely to exhibit reduced medial COP velocity compared to those without PD. The remaining MAO models produced no significant effects. Additionally, the RRC models revealed that self-reported valence and arousal did not significantly predict the COP variables and that the relationship between the level-1 variables and COP movement did not vary significantly across participants. Thus, the IASO models were not conducted for the COP variables in the S2 region.

**S3 Region of the COP Trace**

The RA models indicated significant variation existed among individuals in their AP and ML displacement and velocity of the COP movements in the S3 region on the gait initiation task ($p$’s < .001). The MAO model showed that the participants’ height significantly predicted the anterior COP displacement, $\pi_{04} = -0.226$, $SE = 0.088$; $t(40) = -2.58$, $p = 0.014$. As expected, participants who were taller displayed greater anterior COP displacement in the S3 region. All the remaining models conducted produced no significant results ($p$’s > .05).

**Average Step Length and Step Velocity of the 1st and 2nd Steps**

The RA models showed that significant variation existed among individuals in their length and velocity of the first and second steps of gait initiation. The MAO models revealed that PD predicted the length of step 1, $\pi_{03} = -67.45$, $SE = 25.95$; $t(41) = -2.60$, $p = 0.013$, and the velocity of step 1 $\pi_{03} = -101.53$, $SE = 46.44$; $t(41) = -2.19$, $p = 0.034$. Individuals with PD displayed shorter step lengths and slower step velocity compared to those individuals without PD. Height also predicted the length of step 1, $\pi_{04} = 4.43$, $SE = 1.71$; $t(41) = 2.60$, $p = 0.013$, as well as the length of step 2 (Ht: $\pi_{04} = 4.26$, $SE = 1.38$; $t(41) = 3.08$, $p = 0.004$). Individuals who were taller exhibited longer step lengths.
The RRC model demonstrated that a significant relationship existed between self-reported valence and velocity of the first step, $\pi_{10} = 1.57, SE = 0.56; t(45) = 2.78, p = 0.008$. Exposure to images rated more pleasant, relative to unpleasant, resulted in greater step velocity for the first step of gait initiation. The remaining RRC models were not significant ($p$'s > .05). Additionally, the RRC models revealed that the relationship between the level-1 variables and step length/velocity did not vary significantly across participants so the data were not analyzed with an IASO model.
Figure 4-1. Mean reaction time (Figure 4-1a) and mean percent change scores for reaction time (Figure 4-1b) across category conditions for the PD and Control groups. A=attack, M=mutilation, CM=contamination, E=erotic, HP=happy people, N=neutral, B=blank.
Figure 4-2. COP movement in the S1 region across category conditions for the PD and Control groups for the mean displacement in the posterior direction (Figure 4-2a), mean velocity in the posterior direction (Figure 4-2b), mean displacement in the lateral direction (Figure 4-2c), and mean velocity in the lateral direction (Figure 4-2d). A=attack, M=mutilation, CM=contamination, E=erotic, HP=happy people, N=neutral, B=blank.
Figure 4-3. COP movement percent change scores in the S1 region across category conditions for the PD and Control groups for the mean percent change displacement in the posterior direction (Figure 4-3a), mean percent change velocity in the posterior direction (Figure 4-3b), mean percent change displacement in the lateral direction (Figure 4-3c), and mean percent change velocity in the lateral direction (Figure 4-3d). A=attack, M=mutilation, CM=contamination, E=erotic, HP=happy people.
Figure 4-4. COP movement in the S2 region across category conditions for the PD and Control groups for the mean displacement in the posterior direction (Figure 4-4a), mean velocity in the posterior direction (Figure 4-4b), mean displacement in the medial (Figure 4-4c), and mean velocity in the medial direction (Figure 4-4d). A=attack, M=mutilation, CM=contamination, E=erotic, HP=happy people, N=neutral, B=blank.
Figure 4-5. COP movement percent change scores in the S2 region across category conditions for the PD and Control groups for the mean percent change displacement in the posterior direction (Figure 4-5a), mean percent change velocity in the posterior direction (Figure 4-5b), mean percent change displacement in the medial direction (Figure 4-5c), and mean percent change velocity in the medial direction (Figure 4-5d). A=attack, M=mutilation, CM=contamination, E=erotic, HP=happy people.
Figure 4-6. Mean length of step 1 (Figure 4-6a), mean velocity of step 1 (Figure 4-6b), mean stride length (Figure 4-6c), mean length of step 2 (Figure 4-6d) and mean velocity of step 2 (Figure 4-6e) across category conditions for the PD and Control groups. A=attack, M=mutilation, CM=contamination, E=erotic, HP=happy people, N=neutral, B=blank.
Figure 4-7. Mean percent change scores across category conditions for the PD and Control groups for length of step 1 (Figure 4-7a), velocity of step 1 (Figure 4-7b), length of step 2 (Figure 4-7c), and velocity of step 2 (Figure 4-7d). A=attack, M=mutilation, CM=contamination, E=erotic, HP=happy people.
Figure 4-8. Mean SAM valence ratings (Figure 4-8a) and arousal ratings (Figure 4-8b) across category conditions for the PD and Control groups. The higher a participant’s rating, the more the participant perceived the pictures as being pleasant or arousing, respectively. A=attack, M=mutilation, CM=contamination, E=erotic, HP=happy people, N=neutral.
CHAPTER 5
DISCUSSION

Individuals with PD experience difficulty initiating gait, which is often highly disabling and can interfere with many facets of daily living. Current therapies for patients with PD have shown clear but limited benefits for the treatment of gait disturbances. A pressing need remains to develop novel and complimentary therapeutic strategies to treat these disabling gait symptoms. Gamble and colleagues (in review) recently demonstrated that pleasant emotional states improve the quality of gait initiation in healthy young adults. Manipulation of emotional state may therefore be a viable strategy for optimizing the quality of gait initiation in individuals suffering from PD. The primary aim of the present experiment was to determine the impact of emotional state on the quality of gait initiation in persons with PD and healthy older adults. To address this aim, participants with PD and healthy aged-matched older adults were required to initiate gait and walk several steps following exposure to affective stimuli representing specific emotional categories. Three novel contributions emerged: 1) threatening stimuli speed the initiation of gait for PD patients and healthy older adults, 2) pleasant emotional stimuli facilitate the anticipatory postural adjustments of gait initiation as well as the velocity of the first step for PD patients and healthy older adults, and 3) exposure to emotional stimuli modulates gait initiation parameters in PD patients to the same degree as healthy older adults. Following discussion of these findings, limitations of the present study are addressed, practical implications are suggested, and recommendations for future research are offered.
Reaction Time

Persons with PD have consistently shown deficits on simple reaction time tasks (Gauntlett-Gilbert & Brown, 1998; Burleigh-Jacobs, et al., 1997; Dibble, Nicholson, Shultz, MacWilliams, Marcus, & Moncur, 2004). I therefore hypothesized that PD patients would exhibit slower reaction times on the gait initiation task across all picture conditions relative to the age matched control group. In line with expectations, PD patients reacted more slowly to initiate gait in response to the target initiating stimulus (i.e., picture onset) compared to healthy older adults. While the underlying mechanisms of this deficit have been debated, the delay in movement is likely due to a deficit in central processing of the initiating stimulus (Kutukcu, Marks, Jr., Goodin, & Aminoff, 1998; Cooper, Sagar, Tidwell, & Jordan, 1994). These results support the notion that PD is characterized by the inability to initiate movement (i.e., akinesia) and slowness of willed movement (i.e., bradykinesia).

Consistent with the second hypothesis, exposure to attack pictures speeded the initiation of gait compared to all other pictures categories. The current data support and extend previous evidence showing that exposure to threatening stimuli speeds the initiation of the motor response on a gait initiation task in healthy young adults (Gamble et al., in review), as well as on upper-extremity movement tasks (e.g., ballistic precision pinch grip: Coombes, et al., 2009; wrist extension: Coombes et al., 2007a). Threatening contexts theoretically prime the motor system for action, accelerating motor responses and thereby providing organisms the advantage of efficient fight or flight response (Öhman, et al., 2000; Öhman & Soares, 1998). Furthermore, Coombes et al. (2007a) showed that activating defensive emotional circuitry speeds the initiation of the appropriate motor action by facilitating the central processes that precede overt
movement (i.e., perceptual and cognitive processes necessary to perceive the onset cue and formulate the appropriate motor response). Evidence from the current project corroborates this position and importantly, suggests that the neural circuitry underlying the survival function of the primitive emotion system remains preserved in healthy older adults and those with PD while “on” medication. Indeed, a similar reduction in reaction time (~6%) was observed for PD and control participants in response to attack pictures relative to neutral pictures. While consistent with data acquired from projects that have involved young, healthy subjects, the current findings conflict with those reported in prior research showing that PD patients exhibit blunted reactivity to highly arousing aversive pictures, as indexed by reduced startle eye blink magnitude (Bowers et al. 1996; Miller et al. 2009). Although such evidence might appear contradictory, Miller and colleagues (2009) later specified that the diminished startle potentiation occurred in response to a single subcategory of aversive pictures; namely mutilations. Similar startle reactivity in response to attack, contamination, pleasant and neutral pictures was observed for control and PD participants. Furthermore, Miller et al. were interested in emotion modulation of involuntary movement, which is controlled by different circuits than voluntary movement. Taken together, the findings indicate that PD patients with moderate disease severity experience similar motor and physiological reactivity to threatening stimuli compared to healthy older adults.

Exposure to all other affective pictures led to increased reaction times compared to the neutral pictures for all participants. Prior work has shown that viewing emotional arousing pictures relative to unarousing neutral pictures uses more attentional resources (Bradley, Greenwald, Petry, & Lang, 1992; Cuthbert et al., Schupp, Bradley,
Birbaumer, & Lang, 2000; Lang, Bradley, & Cuthbert, 1998). All participants in the current study rated the affective pictures categories (i.e., erotic, happy people, mutilation, attack, contamination) higher in arousal than the neutral pictures. Thus, even though participants initiated gait following picture offset, the attentional demand of viewing arousing stimuli may have interfered with central processes devoted to movement production, thereby slowing participants’ reaction times. Importantly, attack pictures expedited motor responses on the gait initiation task despite also being rated more arousing and potentially more attentionally demanding than the neutral pictures. Future work should aim to delineate the emotional and attentional contributions to the changes in movement that result from picture viewing contexts.

**Preparatory Postural Adjustments**

The quality of preparatory postural adjustments was indexed via displacement and velocity of the COP movement within the three regions of the COP trajectory during gait initiation. Numerous studies indicate that PD is characterized by inefficient anticipatory postural adjustments during the gait initiation process (Burleigh-Jacobs, et al., 1997; Crenna et al., 1990; Halliday et al., 1998; Gantchev et al, 1996; Hass et al., 2005). Compared to control participants, PD patients in the current study exhibited reduced displacement and velocity of the COP movement in the posterior and lateral directions across all conditions in the S1 region. Furthermore, PD patients exhibited reduced displacement and velocity of the medial COP shift during the weight shift phase compared to control participants. However, the HLM analyses revealed that the differences in medial displacement may have been driven by differences in average height. These results corroborate previous evidence (e.g., Halliday et al., 1998; Crenna et al., 1990) showing that persons with PD have similar qualitative patterns of COP
movement during gait initiation with reduced COP movement amplitude and velocity particularly during the APAs, ultimately causing a lack forward momentum needed to initiate gait.

I also anticipated that exposure to the approach-related picture categories, erotic and happy people, would facilitate the APA’s during gait initiation in the PD and control participants. A previous study found that high and low arousing pleasant pictures relative to unpleasant pictures led to greater displacement and velocity of the posterior and lateral COP movements in the S1 region in healthy young adults (Gamble et al., in review). Furthermore, physiological reactivity to pleasant stimuli has been shown to be similar between persons with PD and healthy older adults (Bowers et al., 1996; Miller et al., 2009). The current study extended these findings, showing that PD and control participants displayed similar increases in posterior displacement of the COP movement following exposure to happy people and erotic pictures compared to attack, mutilation, contamination, and neutral pictures. Furthermore, exposure to both of these approach-related categories enhanced the velocity of the posterior movement compared to attack and contamination pictures. The HLM results showed that self-reported judgments of valence predicted posterior COP movement, thereby providing additional confirmation for the facilitating effect of pleasant stimuli. Specifically, pleasant rated images, relative to unpleasant and neutral, were associated with greater posterior COP displacement and velocity. Importantly, this effect was not modulated by the presence of PD. The initial backward shift of the COP movement, caused by the deactivation of the gastrocnemii and soleus muscles (Winter, 1995), drives the COM forward and thus is responsible for producing the forward momentum needed to initiate gait (Crenna et al.,
The current results suggest that exposure to approach-oriented stimuli may help individuals produce forward momentum during the gait initiation process by augmenting the magnitude and speed of the initial posterior COP movement.

The pleasant picture categories also enhanced the lateral COP movement in the S1 region for all participants. Specifically, the results revealed increased displacement of the lateral movement following exposure to the 1) erotic and happy people pictures compared to mutilation pictures and, 2) happy people pictures compared to the contamination pictures. The HLM analyses supported my hypothesis; revealing greater magnitude and velocity of the lateral COP movement in response to pictures rated more pleasant compared to unpleasant. The initial lateral shift toward the swing limb, caused by the momentary loading of the swing leg by the hip abductors (Winter, 1995), propels the COM toward the stance limb in preparation for single limb support and preserves lateral stability during step execution (Polcyn et al., 1998; Jian et al., 1993; Zettel, McIlroy, & Maki, 2002). Thus, the lateral COP movement in the S1 region is critical to the generation of stance side momentum. The present data indicate that approach-oriented stimuli (i.e., pleasant images) facilitate the momentum needed to reach single limb support during forward gait initiation for both persons with PD and healthy older adults.

The purpose of the COP movement in the S2 and S3 regions is to complete the positioning of body weight over the initial stance limb and then to propel the COM forward, accelerating it away from the stance limb (Jian, Winter, Ishac, & Gilchrist, 1993). The step execution phase of gait initiation is considered to begin when weight
has been transferred from the initial swing limb to the stance limb (Crenna et al., 1990). Compared to the anticipatory postural adjustments (which are more centrally controlled), the S2 and S3 regions represent the beginning of the locomotor phase of gait initiation which is generally regulated by lower level spinal processes (Massion, 1992; Rocchi et al., 2006). Nonetheless, we hypothesized that the approach-related picture categories would facilitate the velocity of the medial COP movement in the S2 region and the velocity of the anterior COP movement in the S3 region compared to all other picture categories. This hypothesis was not supported, as exposure to the affective pictures produced no significant changes in the COP movement in the S2 or S3 region. Gamble et al. (in review) similarly found no impact of emotion in the S2 or S3 regions of the COP trajectory in healthy young adults. Thus, the existing evidence suggests that the effect of emotion on the COP movement during gait initiation is regulated by the anticipatory postural adjustments occurring during the S1 component of GI.

Two explanations are offered to account for the diminished impact of emotion on the COP movement in S2 and S3. First, within the current protocol and in Gamble et al.’s (in review) prior study, participants were instructed to “initiate gait as immediately as possible following picture offset, but walk at your normal pace” as opposed to being instructed to initiate gait and walk as quickly as possible. Hence, participants were required to focus more on the planning aspect of the movement rather than on the locomotor component of the movement. Consequently, emotion’s impact was greatest on S1 of the COP trajectory and RT, the two measures most reflective of motor planning
processes. Perhaps requiring participants to focus on the locomotor aspect of the task (e.g., begin walking as quickly as possible) would lead to modulation of S2 and S3.

Secondly, the idea that emotion’s impact on the preparatory postural adjustments may vary between the APA phase and locomotor phase is supported by animal and human studies. Research has shown that the APA’s (S1) are largely controlled by the SMA, premotor cortex, and basal ganglia (Massion, 1992, Rocchi et al., 2006; Yazaea et al., 1997; Takakusaki et al., 2003), whereas the more automatic locomotor components of gait initiation (i.e., S2, S3) are controlled more so by the brainstem and spinal processes (i.e., CPGs: Takakusaki et al., 2003). Thus, the collective processes controlling the APAs are dissimilar from those that control the locomotor phase of the COP movement. As such the neural circuits regulating the different phases of gait initiation may interact differently with the neural circuits underlying emotional processing.

The results of the current study are in line with evidence suggesting that emotion modulation of movement likely involves higher cortical and subcortical processes. Behavioral work (Coombes et al., 2007a, 2007b) has shown that emotion impacts the speed with which ballistic force is initiated as a function of the impact on centrally driven processes (i.e., cognition, perception), as compared to peripheral processes (i.e., musculature and motor unit recruitment processes). Furthermore, animal retrograde and anterograde tracing studies (Haber, 2003; Haber et al., 2003) and human imaging work (Doron & Goehman, 2010; Schmidt et al., 2009) suggests circuits involving the basal ganglia and frontal cortex are critical to the integration of limbic and motor circuits. Non-reciprocal cortico-cortical and corticothalamic pathways may link multiple frontal cortical
areas and functional basal ganglia-cortical loops, respectively (McFarland & Haber, 2002; Haber & Calzavara, 2009; Schmidt et al., 2009). Thus, information can be relayed from the limbic basal ganglia cortical loop to the motor basal ganglia cortical loop allowing emotion to shape motor processes. Moreover, the SN, as well as the STN, have been identified as potential brain structures which will allow emotion to influence motor processes (Coombes, Corcos, Pavuluri, & Vaillancourt, submitted; Haber, Fudge, & McFarland, 2000). Specifically, it is thought that the different functional regions of the striatum (i.e., limbic, cognitive, motor) are connected via midbrain dopamine neurons, allowing the ventral limbic region of the striatum to interact with the dorsal motor region. Hence, the collective evidence indicates that the neural circuits underlying the APAs involving cortical and subcortical structures, as compared to the locomotor components of gait initiation, are more likely to be influenced by emotion.

It should be noted that the integration of the emotion and motor systems has been evaluated almost exclusively with simple hand movements, and/or in studies that have not differentiated between upper- and lower-extremity control. Importantly, voluntary movement of different body parts engages distinct and somatotopically organized sections of the primary motor cortex (Ehrsson, Geyer, & Naito, 2003; Ghosh et al., 1987). Furthermore, different cerebral control mechanisms may exist for the planning of upper and lower limb movements. For example, mapping of the premotor cortex has demonstrated clear activation differences between hand and foot movements (Wheaton, Carpenter, Mizelle, & Forrester, 2008). Specifically, wrist extension movements elicited activity of the rostral ventral premotor cortex, while ankle dorsiflexion movement elicited activation of dorsal area 6. Similarly, Luft and colleagues
(2002) showed that the distribution of activation across the motor areas substantially differs for isolated elbow and knee movements that share mechanical properties (e.g., corresponding one-dimensional joints, frequency, range). Knee movement evoked greater SMA-proper activation, but less lateralization in M1 compared to the elbow movement. In contrast, other research has shown some common motor representations for isolated flexion and extension movements of the wrist and ankle in the ventral premotor area and parts of the SMA (Ehresson, Fagergren, Jonsson, et al., 1999; Ehresson, Naito, Geyer, et al., 2000). Even so, there appears to be precise effector-specific mapping of motor areas related to planning. Given the distinct effector dependent representations in the motor cortices, future research may want to specify whether different linkages exist between the emotion and motor systems for upper and lower extremity movements. Furthermore, future work should investigate whether emotional input similarly modulates comparable upper and lower extremity movements. Nonetheless, our results suggest that the mechanisms integrating emotion into the motor processes that regulate gait initiation remain intact in PD patients with moderate disease severity while “on” medication.

**Step Execution**

As hypothesized, PD patients exhibited smaller and slower steps during the initiation of gait compared to the healthy older adults. I also predicted that exposure to the approach-related, erotic and happy people pictures would increase the length and velocity of the first two steps compared to all other picture categories. The percent change scores and the HLM analyses partially supported this hypothesis. PD patients showed a greater increase in step velocity of the first step following exposure to the happy people pictures compared to the mutilation pictures (which decreased velocity
compared to neutral). Furthermore, control participants demonstrated a greater increase in step velocity of the first step in response to the erotic, happy people, and mutilation pictures compared to the PD patients’ response to the mutilation pictures. In line with the hypothesis, the HLM analyses revealed that pictures rated more pleasant relative to unpleasant led to greater velocity of the first step. These findings again mirror those of Gamble et al.’s (in review) results in healthy young adults, in which exposure to pleasant images facilitated the velocity of the first step and no effect was found on the second step.

During the step execution phase of gait initiation, individuals achieve a velocity close to steady state velocity (Brunt et al., 1991; Elble, Moody, Leffler, & Sinha, 1994). Prior research has shown that the amplitude and velocity of the posterior COP movement during the APA’s predicts gait velocity at the end of the first step. Thus, the step velocity results, which were relatively small in magnitude, may have been driven by the emotion modulation found in the corresponding APA’s. Specifically, the larger APA’s found following exposure to the happy people and erotic pictures likely enabled a quicker first step.

While the current data collectively indicate a lesser impact of emotion on the stepping components of gait initiation in PD patients and healthy older adults, it would be perfunctory to conclude that emotion has no impact on steady state walking in this population. Prior work has shown emotional influences on steady walking in young adults (Gamble et al., in review; Michalak, Troje, Fischer, Vollmar, Heidenreich, & Schulte, 2009). For example, Gamble and colleagues found that encountering stimuli that clearly motivated a disgust emotional response (i.e., contamination) significantly
shortened stride length and step velocity, whereas stimuli eliciting appetitive-responses
enhanced step velocity during forward walking. A number of methodological
explanations may account for the different effects of emotion on the locomotor
parameters in the Gamble et al. study and the present one. First, the effect of emotion
on locomotion may depend on the component of gait being evaluated (i.e., planning of
the initiation of gait v. regulation of ongoing gait) as well as the nature of the task
instructions (i.e., “walk as soon as possible, but at your normal pace” v. “walk as quickly
as possible”). Secondly, the temporal dynamics of picture presentation and walking
differed between the two studies (i.e., walking at picture offset v. walking while viewing
picture). Future research should investigate whether emotional state impacts steady
state walking in individuals with PD.

Summary

Collectively, the current findings indicated successful integration of the emotion
and movement systems in persons with PD of moderate severity. Threatening pictures
speeded the initial motor response on the gait initiation task, while the approach-related
pictures clearly facilitated gait initiation in all participants, as evidenced by the APAs.
These results support the long held premise that emotions are action dispositions
(Frijda, Kuipers, & ter Schure, 1989; Lang, 1995) and further support the neurobiological
evidence suggesting the emotion and motor systems are integrated in primitive brain
circuits to ensure appropriate motor reactions occur in response to environmental
stimuli (e.g., Pessiglione, et al., 2007; Schmidt, Clery-Melin, Lafarque et al., 2009). As
such, investigating the utilization of the emotion system to optimize movement in PD
could be a promising new avenue for future research. Specifically, inducing pleasant
emotional states to drive improvements in gait initiation may be a viable strategy to
complement existing gait therapies for PD patients with moderate disease severity. These practical implications and future directions are discussed in more detail following the *Limitations* section.

**Limitations**

Several limitations to the current study should be acknowledged. First an imbalance of men and women existed in each group (3 women, > 20 men). Previous work has shown that emotional reactivity to picture stimuli as evidenced by modulation in the human motor system is similar between men and women (Coombes et al., 2008; Gamble et al., in review). Furthermore, with few exceptions (e.g., Bradley, Codispoti, Sabatinelli, & Lang, 2001; Sabatinelli, Flaisch, Bradley, Fitzimmons, & Lang, 2004), research has demonstrated that reactions to affective pictures in the autonomic, somatic, reflex, visual, and evaluative systems are similar between men and women. Women occasion greater defensive reactivity to aversive cues as indexed by facial EMG activity, cardiac deceleration, and judgments of valence and arousal, whereas men are more reactive to pictures with erotic content as evidenced by judgments of valence and arousal and skin conductance (Bradley et al., 2001). Given that (1) the current study’s sample consisted primarily of men, and (2) exposure to erotic pictures drove many of the improvements in gait initiation, replication of these findings in a sample of female PD patients is critical to the generalizability of the results. Importantly, however, gait initiation was similarly facilitated by pictures of happy people, which generate no known gender-based response differences in the evaluative, physiological, or motor systems. As such, we are reasonably confident that the current studies results would be replicated in larger sample of female older adults and PD patients.
Another limitation of the study was the range of disease severity within the current PD sample. Most PD patients were in Hoehn and Yahr stages 2 or 3 and had UPDRS score’s in the 20’s (range: 16-41), indicating a moderate level of disease severity. The HLM analyses indicated that disease severity (UPDRS score) did not impact emotion’s influence on gait initiation. However, this finding may be limited by the lack of patients in the severe stages of the disease, as well as a lack of sufficient power at the between-subject level for the HLM analysis. Pathological changes in limbic structures (e.g., reduction in amygdala volume; Harding et al., 2002; Ouchi et al., 1999) and dopaminergic denervation of limbic-basal ganglia pathways (Braak & Braak, 2000; German et al., 1989; Satton et al., 1982) found in patients with PD likely increase as the disease progresses. Given that midbrain dopamine neurons are likely crucial to the integration of emotional information into motor circuits (Haber, 2003), future studies should include patients with a broader range of disease severity to more comprehensively examine the effect of disease progression on the successful integration of emotion into the functional motor system.

A third limitation centers on the dispositional affect that characterized the sample tested herein. As previously mentioned, PD is increasingly linked with emotional dysfunction, particularly greater symptoms of depression and apathy (Leentjens et al., 2003; Rojo et al., 2003). Such was the case with the current sample. A growing body of research has shown that depression is linked to blunted physiological and motor reactivity to pleasant stimuli (Gamble, Coombes, et al., in review; Larson et al., 2007). Though the HLM analyses revealed, that levels of apathy and depression did not impact the pleasant stimuli’s influence on gait initiation, participants with severe levels of
depression were not included in the study. Our results may not, therefore, generalize to severely depressed PD patients.

Fourth, the data revealed a potential attentional effect of picture viewing on gait initiation performance. Specifically, COP values in the S1 region were primarily reduced in all picture categories relative to the blank condition in which no picture was viewed. Consequently, the direct comparison of movement following the presentation of the affective pictures to the no picture condition likely reflects both attentional and emotional processes. Importantly, the neutral condition was considered to represent the effect of viewing the pictures without the affective component. Hence, this limitation should not compromise the impact of the current findings, as emotion’s effect on gait initiation should be primarily reflected in comparisons between the affective pictures and the neutral pictures (i.e., percent change scores). Future research could extend the current findings by integrating attentional measures or through the use of emotion manipulations of a different modality (i.e., emotionally evocative sounds: Bradley & Lang, 2000).

Additionally, a formal assessment of the COM movement during gait initiation was not conducted, preventing direct inferences to be made regarding the relation between the COP and COM. However, the exclusion of COM data should not detract from the contribution of the current findings. Extensive evidence exists for the interaction between the COP and COM during the preparatory phase of gait initiation (e.g., Breniere et al., 1987; Hass et al., 2005; Martin et al., 2002), allowing for strong inferences to be made from the COP data regarding the influence of emotion on dynamic postural control.
Practical Implications and Future Directions

The findings of the current study provide several potential avenues for future research. First, the results demonstrate that the presentation of pleasant emotional stimuli facilitated gait initiation in PD. Thus, further exploration of emotion manipulations as a strategy to optimize the efficacy of therapeutic interventions to improve gait disturbances may be a promising avenue for future research. For example, researchers should investigate whether emotion manipulations of different modalities can produce similar changes in gait parameters as picture viewing methods. In particular, emotion induction techniques more easily transferable to clinical/real world settings should be explored, such as emotionally evocative sounds, imagery based techniques, or even virtual reality modalities. Common neural representations are known to exist for perceiving emotion in another, feeling an emotion, and imagining an emotion (Holmes, Mathews, Mackintosh, & Dalgleish, 2008; Jabbi, Bastiaansen, & Keysers, 2008). As such, mental imagery may be a particularly effective route to modify emotion in the clinical setting. Furthermore, future research could test interventions designed to up-regulate positive emotional experiences, as well as techniques to facilitate emotional awareness and experience. Emotion awareness and emotion regulation skills could be important, inexpensive tools that persons with PD could use to improve the quality of their movements in any setting.

The present study was a single acute assessment of how emotion influences gait. While the emotion-induced effects on acute bouts of gait initiation may appear to hold little clinical significance (despite their statistical significance), future research could test a chronic intervention in which persons with PD consistently operated in a pleasant, approach-oriented environment. Perhaps the cumulative effects of these small
improvements in movement could lead to more clinically significant and observable changes over time. As such, it will also be important to investigate how clinical settings can be tailored to induce positive emotional states during gait training to maximize improvements in gait.

Alternatively, comparison of gait initiation performance on the pre- and post trials may indicate that repeated heightened activation of the emotion system, regardless of the specific emotion being elicited, enhances motor system activity. The pre- and post-trial comparison was originally conducted to ensure that participants did not experience fatigue, which could have hindered performance on the gait initiation task as the experimental session progressed. Interestingly, all participants improved performance from the pre-trials to the post-trials, as evidenced by greater displacement and velocity of the COP movement during the anticipatory postural adjustments, greater velocity of COP shift from the swing limb to stance limb, and longer and quicker steps. Two likely explanations may account for this change in performance from pre to post trials; motivation to finish the experimental session or physiological mechanisms. With regard to the latter possibility, increased temperature or circulation from the repetitive walking trials could have reduced myofacial restriction and increased joint motion thus allowing for increased gait initiation parameters (Prentice, 2004; Wenos & Konin, 2004).

Concerning the former explanation, broadly increased emotional experience was likely induced during the experimental session. Emotions have long been described as motivational tuned states of readiness (Lang et al., 1998). Repeated activation of the brain’s emotion circuits, regardless of the specific emotion elicited, may increase the intensity of an individual’s current motivational state. In turn, this increased level of
arousal or activation could intensify activation of other response systems, thereby causing a general pattern of heightened motor system excitability. Perhaps gait initiation parameters, which are slower, smaller and less forceful in individuals with PD, can be amplified simply by prolonging or intensifying the experience of emotion.

Individuals with PD in the advanced stage commonly experience freezing of gait; the sudden and transient inability to initiate or continue locomotion (Chee, Murphy, Danoudis, Georgio-Karistianis & Iansek, 2009). While the FOG phenomenon is one of the least understood symptoms of PD, clinicians and researchers agree that FOG does not occur randomly. Indeed, a potential trigger of freezing is thought to be intense emotional stress or threatening situations (Chee, et al., 2009; Rahman, Griffin, Quinn, & Jahanshahi, 2008; Okuma, 2006). This notion has been primarily based upon PD patient reports, rather than systematic investigation. The PD patients in the current study were primarily non-freezers during their “on” state. Therefore, it is possible that PD patients who are “on” freezers may respond to threatening emotional stimuli in a different manner than those PD patients in the current study. It is possible that rather than speeding the initiation of movement, threatening stimuli may induce freezing episodes. Future research needs to systematically investigate the role of emotion as a trigger for FOG in PD. A greater understanding of the factors that induce FOG is crucial to the optimal management of this debilitating mobility problem.

Finally, in the past decade, strides have been made toward greater understanding of the mechanisms allowing emotion to influence motor processes (Coombes et al., in review; Haber, 2003; Revital et al., 2008; Schmidt et al., 2008). Nonetheless, the neural system that allows emotional reactivity to modify and guide
motor behavior remains poorly understood. Future work could manipulate neurosurgical and pharmacological techniques in persons with PD to further investigate the extent to which basal ganglia function and dopamine are integral to the integration of emotion into motor circuits. Past research suggests that basal ganglia pathways consist of two potential neural networks linking emotion and motor circuits via complex nonreciprocal connections which allow a continuous feedforward mechanism of information flow from limbic to motor circuits (Haber, 2003; Haber & Calzavara, 2009). One neural network involves parallel basal gangli-thalamocortical circuits interconnected through feedforward thalamic-cortico-thalamic pathways, while the other network functions via midbrain dopamine neurons of the striato-nigral-striatal pathway interconnecting the functional regions of the striatum (i.e., limbic, cognitive, motor). Individuals with PD could perform the emotion and movement tasks while “on” and “off” dopaminergic medication and DBS of critical basal ganglia structures, such as the STN and SN. Given that a pathological hallmark of PD is the degeneration of dopaminergic cells, discovering an impaired link between the emotion and motor systems while “off” medication would provide additional confirmation for the importance of functioning dopaminergic pathways in connecting these two circuits in the brain. Additionally, performance of tasks while “on” and “off” DBS would allow strong inferences to be made concerning the role of specific basal ganglia structures in emotion and movement integration. For example, replicating the current findings while “on” DBS of the STN, but not “off” DBS, would indicate that the STN is critical to the integration of emotion information into motor systems controlling gait initiation.
Conclusion

The purpose of this investigation was to examine how emotional state alters critical gait parameters in persons with PD and healthy older adults. As hypothesized, patients with PD exhibited slower and diminished amplitude of movement during the gait initiation task compared with the healthy older adults. Despite these expected between group differences, the two groups displayed comparable modulation of gait under emotionally evocative conditions, with both groups responding similarly to the presentation of emotional stimuli. Exposure to threatening stimuli speeded the initiation of the motor response on the gait initiation task, while the approach-related emotional states induced by pleasant pictures clearly facilitated the anticipatory postural adjustments needed to initiate forward gait. The current study provides the first evidence indicating that manipulating the activation of emotional circuits may be a viable strategy to improve the quality of gait initiation in PD patients. With continued empirical efforts, researchers will be able to inform the development of novel emotion-based interventions that may be integrated with other behavioral, pharmacological, and genetic interventions to optimize motor therapy for medication-refractory gait dysfunction in PD.
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The initiation of gait in young, elderly, and Parkinson’s disease subjects

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Suzanne E. Halliday, David A. Winter, James S. Frank, Aftab E. Patla and François Prince

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Kelly Gamble was born in Fort Wayne, IN in 1979, to Mariette and Gary Gamble. Growing up, Kelly was taught that through hard work and a positive attitude she could be successful in all endeavors. Kelly’s work ethic and passion for learning enabled her to be successful in her academic career. Kelly graduated from Scecina Memorial High school in 1997 as valedictorian of her class. Kelly went on to earn a BS in psychology and MA in clinical psychology from the University of Indianapolis. Kelly then enrolled at Ball State University, where she earned a MS in physical education with a specialization in sport psychology. Kelly attended the University of Florida to complete her PhD in health and human performance in 2006. While pursuing her doctorate, Kelly has worked as a research assistant in the Performance Psychology lab and was blessed with great mentors who supported this dream of becoming a Doctor of Philosophy.