**Aesthetics in motion: The beauty of action paintings as
revealed by Parkinson's disease**

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Abstract

Visual art offers cognitive neuroscience an opportunity to study how subjective value is constructed from representations supported by multiple neural systems. A surprising finding in research on aesthetic judgment is that functional activation of motor areas of the brain often occurs in response to static, abstract stimuli, such as paintings. This motor activity has variously been hypothesised to reflect the embodied simulation of an artist's painting movements or emotions, as well as possible preparatory approach-avoidance responses to liked and disliked artworks. However, whether this motor involvement functionally contributes to aesthetic appreciation has not been addressed. Here, we examined whether motor system dysfunction alters the aesthetic experiences of patients with Parkinson's disease. 43 people with Parkinson's disease and 40 controls made preference decisions and rated the motion content and their aesthetic appreciation of a set of high-motion action paintings (by Jackson Pollock) and a set of low-motion neoplastic paintings (by Piet Mondrian). People with Parkinson's disease demonstrated stable and internally consistent preferences for abstract art, but their perception of movement in the paintings was significantly lower in both conditions than that of controls. In addition, people with Parkinson's demonstrated enhanced preferences for high-motion art, and a fundamentally altered relationship between motion and aesthetic appreciation. Our results do not accord well with a straightforward embodied simulation account of aesthetic experiences, because artworks that did not include visual traces of the artist's actions were still experienced as lower in motion by Parkinson's patients. We suggest that the ability to form movement representations from static abstract images is more akin to a process of visual metaphor comprehension that is mediated through the motor system. Overall, we find support for hypotheses linking motion, motor responses and aesthetic appreciation, and provide clear evidence that altered neural functioning changes the way art is perceived and valued.

1. Introduction

Visual art offers cognitive neuroscience an opportunity to study how subjective value is constructed from interactions between multiple neural systems. Experiments in neuroaesthetics suggest that aesthetic experiences engage separable neural systems that represent perceptual and motor information, emotion and value, and semantic knowledge; a model known as the aesthetic triad¹. While most experiments have studied static works of art such as paintings, functional activation of motor areas of the brain has often been found, particularly in response to paintings experienced as especially “dynamic”. Several hypotheses about the nature of this motor activity have been proposed. Some have argued for an embodied simulation account of aesthetic experience, according to which observers simulate the movements and experiences of the painting’s subject or its artist², while others have suggested that motor activity might reflect preparatory approach-avoidance responses to liked and disliked artworks^{3,4}. However, whether motor involvement functionally contributes to aesthetic appreciation or is merely an epiphenomenal byproduct of other processing is not known. To address this question, we examined whether motor system dysfunction alters the aesthetic experiences of patients with Parkinson’s disease (PD). Our study addresses the question of motor involvement in aesthetic valuation generally, as well as in PD specifically.

Both visual motion and motor responses to art have been reported. Studies reporting the former typically used as stimuli artworks which depicted figures or objects in states of implied motion. Activation of visual motion area MT+ was found in response to implied motion in van Gogh paintings⁵, Hokusai Manga⁶, and the dynamic works of Futurism and Cubism⁷. Some studies reporting motor cortex responses to visual art also used representational paintings as stimuli. Corticomotor excitability of an arm muscle was increased when observers viewed a posture involving that muscle in Michaelangelo’s *Expulsion from Paradise*, but not when the viewing the

1 same muscle at rest in other paintings⁸. In a study using similar stimuli, connectivity between
2 dorsal premotor cortex and primary motor cortex was increased when viewing a painting with
3 implied action postures compared to one with static, resting postures⁹.

4
5 While interesting, these results are not specific to aesthetics or visual art perception. They
6 replicate earlier findings from cognitive neuroscience regarding the neural bases of action
7 observation and visual motion perception. The finding that area MT+ is responsive to implied
8 motion in static images was first reported in studies using non-art images of bodies and objects
9 with implied motion^{10–13}. Similarly, premotor and primary motor cortex were shown to respond
10 to static images of human actions^{14,15}.

11
12 A separate line of research suggests that observers are sensitive to the movement information
13 carried in visible brushstrokes in paintings. Features of an artist's original movement, such as
14 trajectory and force, may be preserved in the gestural quality of their brushstrokes, and
15 observers perhaps simulate the parent action from the information contained in its trace². In
16 one study, participants made faster arm movements when the direction of their movement was
17 compatible with the direction of task-irrelevant brushstrokes¹⁶. In an electroencephalography,
18 greater mu rhythm suppression was evoked by Lucio Fontana's slashed canvases compared to
19 control stimuli, which contained similar shapes to the originals but lacked the depth information
20 suggestive of Fontana's cutting actions¹⁷. Similarly, greater activity in motor cortical areas was
21 found when observers viewed Franz Kline's gestural paintings compared to control images in
22 which the movement information was removed¹⁸. Importantly, the paintings used as stimuli in
23 these studies were abstract and did not contain any representational depictions of action or
24 implied motion. Thus, observers are thought to be responsive to visual cues in the way the paint
25 was applied (or the canvas was cut) that imply intentional movements of the artist. However, the
26 fact that motor information can be inferred from the results or traces of movements is, again, not

specific to aesthetics. For example, greater activity in motor and premotor cortex was found when observers viewed handwritten letters compared to printed letters ¹⁹, which was lateralized according to handedness ²⁰. Authorship effects were also observed, where participants more accurately predicted handwriting strokes from parts of self-produced relative to other-produced trajectories ²¹.

For research on motor (or visual motion) responses to art to have something to say about aesthetics, beyond replicating and generalizing non-aesthetics findings to an art context, these motor/motion responses must demonstrably shape the subjective value or meaning one assigns to the object. However, aesthetic responses were often not measured in prior research on this topic ⁶⁻⁹. Some studies that did measure aesthetic responses showed that, in addition to greater motor activity, paintings with implied movement were associated with higher motion and liking ratings relative to control images ^{17,18}, but did not explicitly show a relationship between motion and appreciation. The control stimuli used in these studies were non-art images, and the paintings may have been liked more because of their status as art objects rather than their movement content.

Other works linking motion to aesthetic appreciation provide conflicting evidence on whether this association is positive or negative. Mastandrea and Umiltà ²² found a positive correlation between the amount of perceived motion in a painting and aesthetic appreciation. Thakral et al. ⁵ showed that greater MT+ responses to high motion paintings were greater still when the painting was liked. The most direct evidence of a relationship between motor representations and aesthetic appreciation comes from Ticini et al.²³, who trained participants to make pointillist and stroke style movements with a paintbrush. Liking of pointillist paintings was subsequently enhanced when the paintings were primed with congruent images of appropriate hand grips for

1 making pointillist movements. In a non-art but nevertheless aesthetic context, it was found that
2 people have unconscious motor approach responses towards incidental beautiful faces ²⁴.

3
4 In contrast, other studies suggest a complicated relationship between motion and aesthetic
5 preference. Across a series of studies, compared to neutral paintings, activity in left motor
6 cortex increased in response to paintings classed as ugly, and decreased in response to
7 paintings classed as beautiful ^{3,4}. Similarly, sculptures judged as ugly elicited significantly
8 greater activity in motor cortex than those judged as beautiful ²⁵. Moreover, increasing excitatory
9 activity in motor cortex and inhibitory activity in medial orbitofrontal cortex with transcranial
10 direct current stimulation caused significant decreases in beauty ratings given to artworks ²⁶.
11 Based on these findings, Kawabata and Zeki⁴ proposed that perceiving salient visual stimuli
12 mobilizes the motor system to take some action towards or away from rewarding and aversive
13 objects. Perhaps ugly art is avoided like any other aversive stimulus, but some beautiful art, as
14 an example of a stimulus category that evokes “liking without wanting” ²⁷ does not necessarily
15 evoke approach responses. Previously, it was shown that judgments of facial beauty can be
16 made in the absence of approach motivations ²⁸ Additionally, the most moving aesthetic
17 experiences have not been linked to action but rather to the brain’s default mode network, a
18 task-negative network associated with rest, mind wandering, and self-referential thought ^{29–32}
19 (although see ³³ for a description of how aesthetic emotions are expressed as bodily
20 movements).

21
22 Although embodied simulation and approach-avoidance mechanisms are offered as
23 explanations of motor responses to art, it is not known whether motor involvement functionally
24 contributes to aesthetic experiences or occurs alongside them without shaping judgment. If
25 motor involvement does functionally contribute to aesthetic appreciation, this process should be
26 disrupted in PD patients with neurological motor dysfunction. Although the primary

1 pathophysiology of PD is the loss of dopaminergic neurons in the basal ganglia, dopamine
2 depletion alters regional metabolism, electrophysiologic activity, and functional activation of
3 motor cortex ^{34–36}.

4
5 PD has previously been linked to impairments in representing or simulating actions in motor
6 imagery ^{37,38}, action observation ³⁹, gesture ⁴⁰, and language ^{41,42}, although language effects
7 predicted by simulation accounts are not always consistently observed ⁴³. One other study to
8 date has examined changes in aesthetic appreciation in people with PD ⁴⁴. In this study,
9 participants completed the Assessment of Art Attributes ⁴⁵ along with liking and beauty ratings
10 on a set of 15 paintings. People with PD rated the artworks as higher in emotionality, but
11 otherwise gave similar ratings to controls. Critically, this study did not investigate the
12 relationship between motor and aesthetic responses, and therefore did not include a motion
13 rating.

14
15 To test the hypothesis that the brain's motor system functionally contributes to aesthetic
16 experiences, we examined whether aesthetic judgments, motion ratings, and the relationships
17 between them were altered in patients with neural motor dysfunction. Participants were exposed
18 to two sets of abstract paintings. The first set, dominated by intensely dynamic movement, were
19 action paintings by Jackson Pollock (the “high-motion” condition). The second set, characterized
20 by the meticulous use of straight lines, color blocking, and an absence of gestural strokes, were
21 neoplastic paintings by Piet Mondrian (the “low-motion” condition). Our hypothesis led to the
22 following testable predictions for the relationship between motor system integrity, motion, and
23 aesthetic valuation.

24
25 1. If motion is not involved in aesthetic valuation, then no systematic relationship will be found
26 between motion and people's valuation ratings.

2. If general dysfunction of striatal reward and executive processing results in disruptions in aesthetic appreciation, then people with PD will have altered or erratic aesthetic valuations that are not associated directly with or specific to motion characteristics of artwork.

3. If the motor system typically allows one to understand and appreciate the artist's actions and intentions as expressed in motion in artwork (see embodied simulation account: Freedberg & Gallese, 2007) then people with PD will have altered aesthetic valuations of art work as related to art's motion characteristics.

a. If people with PD are unable to form movement representations their valuations of artwork as related to motion will be erratic and different than controls.

b. If people with PD can form movement presentations, but these representations are altered systematically, their valuations of artworks as related to motion will be internally consistent but different than controls.

2. Method

2.1. Participants

Table 1. Participant demographics and clinical features of the PD group.

	Parkinson's	Control
Age	67.84 (8.13)	69.5 (7.77)
Education	16.91 (2.0)	17.4 (3.16)
Gender	23 M, 20 F	14 M, 26 F
Disease Duration	7.79 (4.13)	

UPDRS-motor	23.76 (9.46)
Levodopa Equivalent Dose	701.86 (404.89)
Hoehn & Yahr stage	Stage 1 = 1
	Stage 2 = 29
	Stage 3 = 12
	Stage 4 = 0
	Stage 5 = 1

43 PD patients were recruited from the Parkinson's Disease and Movement Disorders Center at Pennsylvania Hospital. 40 control subjects, matched to the patients on age and education, were recruited from two elderly control research databases maintained by the Penn Center for Cognitive Neuroscience and the Penn Memory Center. Participants were eligible if they were cognitively normal (i.e. not meeting criteria for a diagnosis of dementia or mild cognitive impairment). PD participants' cognitive status was determined at the most recent expert consensus meeting at Pennsylvania Hospital prior to their testing appointment. Participants were excluded if they had a diagnosis of any other neurological disease other than PD, if they had ever had a stroke or a traumatic brain injury, if they had undergone deep brain stimulation, or if they had an uncorrected visual impairment. Participants were tested on their usual medication either at home or at Pennsylvania Hospital. Demographic and clinical features of the participant groups are reported in Table 1.

2.2. Materials

A set of 10 action paintings by Jackson Pollock and 10 neoplastic paintings by Piet Mondrian were used as materials in two experimental tasks. High resolution photographs of the paintings

were downloaded from museum websites under the fair use doctrine of US copyright law. Noncommercial educational uses (e.g. scholarship, research, teaching) of copyrighted materials are considered “fair use” and are allowed without express permission from the copyright holder. A list of the selected paintings is included in the appendix of this paper.

The selected paintings were drawn from a larger set of 34 Pollock paintings and 40 Mondrian paintings which were normed online (see Supplementary Materials for information on the norming procedure). Critically, and consistent with our assumptions about the action paintings, the Pollocks were rated by the norming sample as significantly and substantially higher for motion than the Mondrian paintings. The 10 Pollocks and 10 Mondrians used in this study were selected to retain motion differences and minimize liking and beauty differences between conditions, to ensure that the conditions were well-matched in difficulty. In the experimental set, the Pollocks received higher normed ratings than the Mondrians for motion, complexity, and interest, the Mondrians received higher normed ratings than the Pollocks for familiarity and balance, but there were no significant differences between the two sets of paintings on beauty and liking (see Table 3 below).

Table 3. Normative ratings of the experimental set.

Rating	Mondrian	Pollock	t	p	Cohen’s d	95% Confidence Interval	
						Lower	Upper
Motion	2.36 (.71)	5.51 (.64)	-10.41	< .001	-4.655	-3.793	-2.519
Familiarity	3.66 (.56)	2.80 (.31)	4.24	< .001	1.898	0.433	1.283
Beauty	3.58 (.45)	3.75 (.51)	-0.80	0.436	-0.356	-0.619	0.279
Interest	3.38 (.85)	4.74 (.29)	-4.79	< .001	-2.141	-1.957	-0.763
Liking	3.63 (.55)	3.91 (.48)	-1.21	0.243	-0.540	-0.768	0.208

Complexity	2.76 (1.08)	5.41 (.49)	-7.01	< .001	-3.136	-3.434	-1.850
Balance	4.91 (.35)	3.97 (.37)	5.78	< .001	2.583	0.597	1.279
Hue	3.63 (.75)	3.88 (.43)	-0.92	0.372	-0.409	-0.824	0.324
Saturation	3.85 (1.17)	3.89 (.8)	-0.10	0.919	-0.046	-0.988	0.896

2.3. Procedure

Participants were first shown the full set of 20 paintings to familiarize them with the works. The paintings were presented in a random order for each subject using E-Prime. Each painting appeared on the screen for 5 seconds and was preceded by a 1 second fixation cross. Participants were instructed to simply look and pay attention to the images.

2.3.1. Two-alternative forced choice task

Following the familiarization, participants completed a two-alternative forced choice (2AFC) task that tested the internal consistency of their own preference judgments. Pairs of paintings within each artist were presented side by side. Participants indicated which painting they preferred. Each set of 10 paintings results in 45 possible pairs. Each of the 45 pairs was shown to the participants three times, for a total of 135 pairs of Pollocks and 135 pairs of Mondrians. There was no time limit on participants' choice decisions.

2.3.2. Ratings task

Finally, participants rated the paintings along the same nine dimensions as in the norming study (personal-evaluative: Liking, Beauty, Interest, Familiarity, formal-composition: Motion,

Complexity, Balance, Color-Hue, Color-Saturation). The Color dimensions served as relatively objective control ratings to check that the patients were able to rate sensibly. Paintings were presented in random order and participants completed all nine ratings on each painting before moving to the next item.

2.4. Data Analysis

2.4.1. 2AFC Analysis

Subject-specific preference scores were calculated for each painting by dividing the number of times the painting was chosen by the number of times it was presented (27). For each subject, the paintings from each artist were then ranked in order from most preferred to least preferred. Paintings selected an equal number of times received tied ranks. These ranks were then used to identify transitivity violations, i.e., when participants selected a less preferred painting over a more preferred painting, according to their own ranked order. The distance of each transitivity violation was also scored, which was the difference in rank between the two paintings. Decisions between tied ranks were not counted as violations. The number of transitivity violations per artist was counted for each subject, along with average violation distances. A 2 x 2 mixed ANOVA with Artist (Pollock/Mondrian) and Group (PD/control) as fixed factors was used to analyse these data.

2.4.2. Ratings Analysis

Item-level ratings were retained for each subject. Linear-mixed effects models were used to analyse these data, to account for variability in both subjects and items. All subjects participated in both artist conditions. We thus specified the mixed-effects models to include random

intercepts for painting, and by-subject random slopes for the Artist conditions. We analysed the effect of Group, Artist, and their interaction on each rating separately, and the fixed and random effects structure was identical for each model:

Rating Dimension ~ Group * Artist + (1 | Painting) + (Artist | Subject)

Models were constructed using the lme4 package in R (version 3.6.3), and p-values were estimated using the lmerTest package.

3. Results

3.1. 2AFC Preference Transitivity

The number of transitivity violations participants made in their forced choice preference decisions was not significantly affected by Group ($F(1,81) = .15, p = .7, \eta_p^2 = .002$), Artist ($F(1,81) = 2.01, p = .16, \eta_p^2 = .024$), or their interaction ($F(1,81) = .96, p = .33, \eta_p^2 = .012$). The size of transitivity error distances was similarly not significantly affected by Group ($F(1,81) = 1.52, p = .22, \eta_p^2 = .018$), Artist ($F(1,81) = .13, p = .72, \eta_p^2 = .002$), or their interaction ($F(1,81) = 2.04, p = .16, \eta_p^2 = .025$). Transitivity means and SDs are reported in Table 4.

Table 4. Descriptive statistics for the 2AFC preference transitivity task.

Artist	Group	Transitivity Violations		Error Distance	
		Mean	SD	Mean	SD
Mondrian	NC	8.85	4.99	1.72	0.61
	PD	8.58	5.11	1.54	0.35
Pollock	NC	9.13	5.14	1.59	0.41

3.2. Personal-Evaluative Ratings

Familiarity ratings were not significantly affected by Group ($\beta = .05$, $SE = .40$, $t = .12$, $p = .906$), Artist ($\beta = .43$, $SE = .23$, $t = 1.86$, $p = .068$), or their interaction ($\beta = .23$, $SE = .24$, $t = .92$, $p = .358$). The analysis of Beauty ratings revealed a significant interaction between Group and Artist ($\beta = .54$, $SE = .21$, $t = 2.50$, $p = .014$), such that controls gave higher Beauty ratings to the Mondrians than the PD patients, while the PD patients gave higher Beauty ratings to the Pollocks than the controls. A very similar interaction between Group and Artist was also found for Liking ratings ($\beta = .6$, $SE = .24$, $t = 2.50$, $p = .015$), and for Interest ratings ($\beta = .62$, $SE = .21$, $t = 2.90$, $p = .005$). Overall, controls preferred Mondrian paintings and PD patients preferred Pollocks (ratings summarized in Figure 1. below).

3.3. Formal-Composition Ratings

For Motion ratings, there was a significant main effect of Artist, confirming that the Pollock paintings were perceived as being higher in Motion than the Mondrians ($\beta = 2.32$, $SE = .41$, $t = 5.72$, $p < .001$). There was also a significant main effect of Group ($\beta = .82$, $SE = .26$, $t = 3.16$, $p = .002$), such that PD patients systematically gave lower Motion ratings across both sets of paintings. There was no significant interaction between Group and Artist ($\beta = .36$, $SE = .26$, $t = 1.38$, $p = .17$).

Pollocks were rated higher in Complexity than Mondrians ($\beta = 1.73$, $SE = .45$, $t = 3.85$, $p < .001$), but there was no significant effect of Group ($\beta = .15$, $SE = .20$, $t = .77$, $p = .45$) and no

interaction ($\beta = .09$, $SE = .22$, $t = .39$, $p = .70$). No significant effects were found for Balance, Hue, or Saturation ratings (see Figure 1).

Figure 1. Ratings of the paintings split by Artist and Group.

3.4. Relationships Between Motion, Appreciation, and Complexity

To summarize the results so far, we found that aesthetic appreciation was predicted by the interaction between Group and Artist. Across Liking, Beauty, and Interest, the Mondrians were appreciated more by the controls than the PD patients, while the Pollocks were appreciated more by the PD patients than the controls. Motion was the only rating characterized by a significant main effect of Group, with PD patients giving significantly lower Motion ratings across

1 the board. Next, we examined whether the relationship between Motion and appreciation was
2 altered in PD.

3
4 Given that ratings were recorded at the trial level (i.e. each subject's responses to each
5 painting), a traditional correlation approach would not accurately capture the data structure.
6 Averaging each participant's ratings across the paintings fails to capture variability in the
7 paintings themselves. On the other hand, correlating at the level of the item does not account
8 for the variance explained by subjects. To account for both by-item and by-subject variance, we
9 used the "correlation" package in R to analyze correlations between the ratings with a multilevel
10 approach that included random effects for Subject and Painting. Note that N is large enough
11 under this approach, given the number of data points (1597), that even weak correlations are
12 statistically significant. Greater weight should be given to r than p values when evaluating the
13 practical significance of these correlations.

14
15 Not surprisingly, the three evaluative ratings (Liking, Beauty, and Interest) were all highly
16 correlated with each other. Liked paintings were beautiful ($r(1595) = .82, p < .001$), beautiful
17 paintings were interesting ($r(1595) = .68, p < .001$), and interesting paintings were liked ($r(1595)$
18 $= .77, p < .001$). Motion and Complexity ratings were not strongly correlated with each other
19 ($r(1595) = .33, p < .001$), with Complexity ratings accounting for only 10.89% of the variance in
20 Motion. While the Pollock paintings were higher in both Motion and Complexity than the
21 Mondrians, the minimal association between these variables suggests that effects observed in
22 Motion ratings are not driven by greater Complexity. Correlation strengths are illustrated in
23 Figure 2 below.

Figure 2. Correlation strength between ratings. Control ratings of non-interest (Hue and Saturation) excluded for clarity.

Next, we tested whether impairments in perceiving Motion in the PD group altered the relationship between Motion and appreciation (Beauty and Liking). While the linear correlation strengths between Motion and Liking ($r(1595) = .2, p < .001$) and Motion and Beauty ($r(1595) = .2, p < .001$) were low, scatterplots suggested that the relationships were quadratic rather than linear. For both Beauty and Liking as dependent variables, three mixed models were constructed to test the interaction between Group and Motion ratings, with Motion's relationship to Beauty and Liking treated as 1) linear, 2) quadratic, and 3) cubic. Model comparisons

revealed that both types of polynomial regression outperformed the linear regression, but the cubic model did not improve on the quadratic model. Here we report the models with quadratic terms for Motion.

The interaction between Group and Motion significantly predicted Beauty ($\beta = 7.35$, $SE = 3.32$, $t = 2.22$, $p = .027$) and Liking ratings ($\beta = 7.78$, $SE = 3.75$, $t = 2.08$, $p = .038$). Figures 3 and 4 illustrate the results of these models. Controls demonstrate a quadratic relationship between Motion and Beauty/Liking, where increases in Motion at the low end are liked while increases in Motion at the high end are disliked. This relationship is markedly different for PD patients, who demonstrate a linear relationship between Motion and Beauty/Liking.

Figure 3. Fitted values from the model testing the effect of Group and Motion ratings on Beauty ratings.

Figure 4. Fitted values from the model testing the effect of Group and Motion ratings on Liking ratings.

To test the specificity of this relationship, we ran the same analysis procedure with Complexity ratings instead of Motion. Unlike the previous analyses with Motion ratings, model comparisons revealed that including polynomial terms for Complexity did not fit the data better than linear models. While the interaction between Group and Complexity also predicted Beauty ($\beta = .13$, $SE = .05$, $t = 2.6$, $p = .009$) and Liking ($\beta = .15$, $SE = .05$, $t = 2.73$, $p = .006$), figures 5 and 6 illustrate that these relationships differed between groups in slope rather than in shape, with PD patients demonstrating a slightly stronger relationship between Complexity and appreciation.

1
2 Figure 5. Fitted values from the model testing the effect of Group and Complexity ratings on
3 Beauty ratings.

4

5
6 Figure 6. Fitted values from the model testing the effect of Group and Complexity ratings on
7 Liking ratings.

4. Discussion

Motivated by the common observation that the motor system is engaged in response to visual art, this study tested the hypothesis that the motor system functionally contributes to aesthetic experiences. In a study sample that was large compared to typical patient samples in neuropsychology, we examined how motor system dysfunction in PD affects aesthetic appreciation, the perception of motion in art, and the relationship between these variables. Our investigation provides several notable findings demonstrating that motor integrity of the viewer and motion characteristics of paintings contribute to aesthetic experiences.

At the most basic level, our data confirm the hypothesis that motion contributes to aesthetic experiences. People can infer degrees of movement in abstract paintings that are neither themselves moving nor depicting moving objects. These representations of movement are then systematically related to people's aesthetic evaluation, whether they are healthy controls or people with PD.

We can also dispense with another general hypothesis. One could imagine that striatal dysfunction would impair aesthetic valuation in general. On this account, people with PD would make aesthetic judgments that differed from healthy controls regardless of the attributes or painting under consideration. One might even predict that their judgments would be erratic in the 2AFC task for both Pollock and Mondrian paintings. This prediction was countered by the observation that healthy controls and people with PD were similarly consistent in their comparisons of paintings. Despite this internal consistency, as we describe below, people with PD did have altered aesthetic valuation of paintings as related to motion attributes.

1
2 Across both high-motion action paintings and low-motion neoplastic paintings, people with PD
3 gave consistently lower ratings of the amount of movement present in the art. In fact, across
4 nine rated dimensions, Motion was the only feature characterized by a main effect of Group.
5 This finding provides evidence that the brain's motor system is involved in translating non-
6 representational information from static visual cues in the image into representations of
7 movement. There are several possible explanations for this effect. First, as proposed by the
8 embodied simulation account of aesthetics, observers may be able to simulate the movements
9 of artists by observing the traces of their gestural strokes in the paint ². Under this view, the
10 drips and flings of paint on Jackson Pollock's canvases are represented in the brains of
11 observers as the bodily actions required to produce those splatters. If true, our results would
12 suggest that PD patients are less able to translate paint traces into motor programs of the
13 actions required to produce those patterns.

14
15 However, the fact that Mondrian's neoplastic works were also rated significantly higher in motion
16 by controls relative to PD patients does not cohere well with this interpretation. Mondrian's
17 fastidious style is notable for the *absence* of gestural strokes in his geometric abstractions,
18 which contrast starkly with Pollock's gestural abstractions. If there are no visible movement
19 traces from which observers can simulate actions, to what are participants reacting when they
20 rate the movement content of Mondrian paintings? The Mondrian paintings receiving the highest
21 motion ratings in this study contained more visual elements, overlapping lines, repetition, and
22 many small areas of contrasting colors. Mondrian's final *Boogie-Woogie* paintings, inspired by
23 the New York jazz scene, are viewed as dynamic and rhythmic, despite an absence of gestural
24 brushwork. The grids of yellow lines intersecting with red and blue squares are compared to
25 New York's grid layout, the movement of traffic, blinking lights, and the stuttering rhythms of
26 jazz. It is possible that perception of movement in works like these may be more akin to a

process of visual metaphor comprehension, leading to abstract representations of movement rather than simulations of specific bodily actions. Similarly, Pollock paintings may be felt as dynamic because the increasing number of overlapping colors and the manner of paint application leads to more repetition, curvature, and contrast, which are thought to evoke feelings of movement ⁴⁶.

While the data reported here cannot differentiate the exact mechanism by which motion is perceived in art, they do suggest that dysfunction of the cortico-subcortical motor circuit impairs the process of forming such movement representations. While PD is a heterogenous disease, the patients studied here were early in the natural course of their disease, presenting with motor symptoms but normal cognition. Nevertheless, it is possible that if judging the motion content of art requires abstract, relational thinking rather than action simulation, subtle cognitive impairments not captured by standard instruments could account for the impairments seen in the PD patients. However, the fact that Motion was the only non-evaluative rating affected in PD argues against this possibility. Judgments of other concepts like Balance and Complexity might also be expected to be impaired if the judgment of motion content was driven by general cognitive impairment. Additionally, people with PD demonstrated very similar levels of transitive preferences to the controls on the 2AFC task. This suggests that the patients were making sensible judgments that were internally consistent with respect to their own preferences. Moreover, on two relatively objective ratings – Hue and Saturation – the PD patients were again indistinguishable from controls, suggesting that their general ability to judge formal aspects of an image remain intact.

Turning to the valuation ratings of the paintings – Beauty, Liking, and Interest – at a first pass, one might be surprised to observe that the PD group demonstrated *increased* preferences for the Pollocks compared to the controls, while the controls appreciated the Mondrians more than

1 the patients. A straightforward prediction is that people with PD would dislike Pollock paintings
2 and be indistinguishable from controls with Mondrian paintings. Again, our finding does not
3 accord well with an embodied simulation account of aesthetics, which proposes that simulation
4 allows us to empathise with, understand, and connect with the artist's feelings and intentions.
5 Why should PD lead to an apparently enhanced appreciation of action paintings? Our analysis
6 of the relationship between motion and preference ratings sheds some light on this issue.

7
8 While the linear correlation strength between motion and the various appreciation ratings was
9 low, visual inspection of the data suggested that the relationship could be quadratic. Polynomial
10 regressions confirmed this, with models including quadratic terms for the motion-preference
11 relationship outperforming those which included only linear terms. The interaction between
12 Group and Motion ratings significantly predicted both Beauty and Liking ratings. Plots of the
13 fitted regression models (Figs 3 and 4) demonstrate that the relationship between motion and
14 aesthetic appreciation was quadratic in controls, but linear in patients. For controls, increases in
15 motion at the low end of the scale were associated with increasing appreciation, while increases
16 in motion at the high end of the scale predicted decreasing appreciation. Given that PD patients
17 gave significantly lower motion ratings across the board, their apparently linear relationship
18 between motion and appreciation may reflect that their limited perception of motion falls on the
19 ascending side of the curve. Beyond basal ganglia dysfunction, PD is associated with abnormal
20 functional activity in primary motor cortex ³⁵. If motor cortex is underactivated during art
21 observation in PD, the normal processing that leads to increased motor activity during
22 experiences of aesthetic displeasure is likely to be disrupted, but in a systematic way. The
23 leftward shift in forming movement representations in people with PD would still result in
24 internally consistent ratings as we observed in the 2AFC results.

1 The observed quadratic relationship between motion and aesthetic appreciation may help to
2 clarify inconsistent findings in prior research. While some studies linked increased motion to
3 increased preference ^{5,22,23}, others found a negative relationship ^{3,4,25}. We suggest the reason for
4 this discrepancy is that the stimuli used in these studies may have been sampling different parts
5 of the quadratic relationship.

6
7 Finally, it is worth emphasizing that the motion effects found in this study cannot be attributed to
8 greater complexity in the higher motion paintings. Objectively, it is true that the paintings rated
9 highest for motion tended to also be rated as more visually complex. However, Motion and
10 Complexity ratings were only correlated at .33, while more overlapping concepts like Beauty and
11 Liking were correlated at .82. We found no significant differences in the Complexity ratings
12 given by patients and controls, while Motion ratings were significantly lower in the patients.
13 Furthermore, while the relationship between aesthetic appreciation and motion ratings was
14 markedly different for patients and controls, the relationship between appreciation and
15 complexity was different in strength rather than in shape. PD patients demonstrated a steeper
16 linear relationship between complexity and appreciation, which suggests they may find more
17 visually intense stimuli the most appealing.

18 19 4.1. Conclusion

20
21 Art appreciation is considered essential to human experience. This study provides clear
22 evidence that altered neural functioning changes the way art is perceived and valued. People
23 with neurological motor dysfunction demonstrated decreased experiences of motion in art,
24 enhanced preferences for high-motion art, and a fundamentally altered relationship between
25 motion and aesthetic appreciation. Our results do not accord well with a straightforward
26 embodied simulation account of aesthetics, because artworks that did not include visual traces

1 of the artist's actions were still experienced as lower in motion by people with PD. We suggest
2 that visual features such as contrast, repetition, number of elements, and curvature may be
3 apprehended metaphorically as abstract representations of movement rather than simulated as
4 actions. Overall, we find support for hypotheses linking motion, motor responses and aesthetic
5 appreciation. People with PD have altered art appreciation that is linked specifically to their
6 altered ability to form movement representations from static abstract images.

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Authorship Statement

All authors contributed to the conception and design of the study. SH and JR acquired the data, and SH analysed the data. SH and AC interpreted the data and drafted the manuscript, and DW and JR provided revisions.

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- 1 Appendix
- 2 List of paintings used as stimuli
- 3 Jackson Pollock paintings:
 - 4 1. Eyes in the heat, 1946
 - 5 2. Alchemy, 1947
 - 6 3. Number 1A, 1948
 - 7 4. Number 3, 1948
 - 8 5. Untitled (Green Silver), 1949
 - 9 6. Number 1, 1949
 - 10 7. Autumn Rhythm (Number 30), 1950
 - 11 8. Number 18, 1950
 - 12 9. Convergence, 1952
 - 13 10. The Deep, 1953
- 14 Piet Mondrian paintings:
 - 15 1. Tableau No. 2/Composition No. VII, 1913
 - 16 2. Composition No. VI, Composition 9 (Blue Façade), 1914
 - 17 3. Composition No. 10 (Pier and Ocean), 1915
 - 18 4. Composition with Large Red Plane, Yellow, Black, Gray and Blue, 1921
 - 19 5. Lozenge Composition with Yellow, Black, Blue, Red, and Gray, 1921
 - 20 6. Tableau I: Lozenge with Four Lines and Gray, 1926
 - 21 7. Composition No. II, with Red and Blue, 1929
 - 22 8. Composition in White, Black, and Red, 1936
 - 23 9. Composition with Yellow, Blue and Red, 1942
 - 24 10. Victory Boogie Woogie, 1944