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The Varieties of Momentum-Like Experience

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Cognition and behavior exhibit biases consistent with future expectations, and some of these biases result in momentum-like effects and have been linked with the idea of momentum. These momentum-like effects include representational momentum, operational momentum, attentional momentum, behavioral momentum, and psychological momentum. Effects of numerous variables involving characteristics of the target, display, context, or observer on each momentum-like effect are considered, and similarities of different momentum-like effects are considered. It is suggested that representational momentum, operational momentum, and attentional momentum reflect similar or overlapping mechanisms based on a perceptual time-scale and extrapolation primarily across space, and that behavioral momentum and psychological momentum reflect similar or overlapping mechanisms based on a longer time-scale and extrapolation primarily across time. It is further suggested that all 5 forms of momentum-like effect could reflect a more general extrapolation mechanism that anticipates the future action, behavior, or outcome of a given target, person, or process. A list of properties characterizing momentum-like effects is proposed, and constraints and issues relevant to future models of momentum-like effects are discussed.

Keywords: representational momentum, operational momentum, attentional momentum, behavioral momentum, psychological momentum

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The cognitive or behavioral representation of a stimulus is often shifted (displaced) forward in space and time in ways that continue the current action or behavior or anticipate the future action or behavior of that stimulus. This forward shift has been found with many different types of stimuli, and different names have been given to these forward shifts in different types of stimuli. A common element of these different names is the word "momentum," and examples include representational momentum (e.g., Freyd & Finke, 1984), operational momentum (e.g., McCrink, Dehaene, & Dehaene-Lambertz, 2007), attentional momentum (e.g., Pratt, Spalek, & Bradshaw, 1999), behavioral momentum (e.g., Nevin, Mandell, & Atak, 1983), and psychological momentum (e.g., Vallerand, Colavecchio, & Pelletier, 1988). Despite use of the word "momentum" in the names given to these shifts in different types of stimuli, the literatures on these different momentum-like effects have had relatively little contact. Thus, one purpose here is to examine potential similarities of these momentum-like effects, and a second purpose here is to consider whether these momentum-like effects are separate phenomena or result from similar or overlapping mechanisms. Full reviews of each type of momentum-like effect are beyond the scope of this article, but findings regarding whether the same variables influence different momentum-like effects in similar ways, and findings relevant to comparisons of different momentum-like effects, are considered. A list of properties of momentum-like effects is proposed, and constraints on future models of momentum-like effects are addressed.

One conclusion that will be reached is that different momentum-like effects are related and result from similar or overlapping mechanisms. Such mechanisms are not tied to physical momentum, but instead reflect a more general change in an abstract feature space. Representational momentum, operational momentum, and attentional momentum are highly similar and might reflect similar or overlapping mechanisms. Furthermore, behavioral momentum and psychological momentum are highly similar and might reflect a different set of similar or overlapping mechanisms. A second conclusion that will be reached is that momentum-like effects exhibit several properties that facilitate anticipation of the future action, behavior, or outcome of the represented target, person, or process. Such anticipations do not necessarily reflect physical reality (e.g., representational momentum [Kozhevnikov & Hegarty, 2001] and psychological momentum [Markman & Guenther, 2007] can reflect notions of impetus) and can be influenced in varying degrees by an individual's beliefs and expectations. A third conclusion that will be reached is that although the names of different momentum-like effects include the word "momentum," the extent to which each momentum-like effect involves actual momentum within a psychological process varies across different types of momentum-like effects. Part 1 presents brief descriptions of each momentum-like effect. Part 2 describes influences of different variables on momentum-like effects, and Part 3 compares different momentum-like effects. Part 4 considers properties of momentum-like effects, and Part 5 suggests issues to be addressed by future models of momentum-like effects. Part 6 presents a summary and some conclusions.

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Part 1: Types of Momentum-Like Effect

Physical momentum is defined as the product of velocity and mass. Each momentum-like effect considered here involves an analogy with physical momentum in which the rate of change or response corresponds to velocity and in which the size, importance, or resistance to change corresponds to mass, and these correspondences are listed in Table 1. Such an analogy has been referred to as the *momentum metaphor* (e.g., Hubbard, 2010; Markman & Guenther, 2007; Nevin & Grace, 2000). Although momentum-like effects involve influences of previous actions, behaviors, and outcomes on subsequent actions, behaviors, and outcomes, not all influences of previous actions, behaviors, and outcomes on subsequent actions, behaviors, and outcomes are momentum-like effects. Momentum-like effects are limited to cases in which there is a continuation of the activity, behavior, or outcome of a specific target, person, or process. Thus, examples in which an influence of one stimulus is passed to another stimulus (e.g., one word priming subsequent processing of a semantically related word; a mood induction procedure priming subsequent recognition of a particular affective stimulus) would not be considered momentum-like effects. In Part 1, the nature of each momentum-like effect, and a typical experiment that demonstrates each type of momentum-like effect, are briefly described.

Representational Momentum

Representational momentum involves displacement of the judged position of a moving target in the direction of anticipated motion (e.g., if a target moves from left to right, the judged final position of the target is displaced slightly to the right; if a target moves from right to left, the judged final position of the target is displaced slightly to the left). In a typical experiment on representational momentum, a participant views a smoothly (i.e., continuously) moving target (e.g., Hubbard, 1990) or a sequence of static inducing stimuli that are each spatially offset from the preceding stimulus to imply target motion (see Panel A in Figure 1) in a consistent direction (e.g., Freyd & Finke, 1984). After the target vanishes, the participant judges whether a subsequently presented probe is at the final target location (e.g., Freyd & Finke, 1984) or indicates the final target location by positioning a mouse cursor (e.g., Hubbard, 1990) or by touching the appropriate location in the display (e.g., Ashida, 2004). Participants are more likely to respond *same* to probes shifted slightly further in the direction of motion (see Panel B in Figure 1) or to position the cursor or touch a location shifted slightly further in the direction of motion. This forward displacement in judged final position has been referred to as *representational momentum* (e.g., Freyd & Finke, 1984; see reviews in Hubbard, 1995c, 2005b, 2014a). Empirical findings regarding representational momentum are summarized in Appendix A, and a detailed review of theories and models of representational momentum is provided in Hubbard (2010).

Operational Momentum

Whereas representational momentum typically involves movement in physical space, operational momentum involves movement in numeric space (i.e., along a mental number line). Just as there is a forward displacement in physical space of the final location of a moving target, so too does there appear to be a forward displacement in numeric space as a result of carrying out an arithmetic operation that implies movement along a mental number line. If experimental participants give their impression of the magnitude of the sum or difference of two quantities, they generally overestimate the sum of an addition (that involves rightward movement along a mental number line) and underestimate the difference of a subtraction (that involves leftward movement along a mental number line). In a typical experiment on operational momentum (e.g., Knops, Zitzmann, & McCrink, 2013; McCrink et al., 2007), participants view a cluster of moving dots that disappears behind a barrier. Another cluster of moving dots then disappears behind the barrier (addition) or a smaller cluster of moving dots exits from behind the barrier (subtraction). The barrier vanishes, and participants indicate which of several simultaneously presented probe dot clusters reflects the number of dots that should have been behind the barrier when the barrier vanished. Participants typically indicate clusters larger than the correct sum with addition and clusters smaller than the correct difference with subtraction (i.e., the response is further along a mental number line in the direction specified by the operator), and this has been referred to as *operational momentum* (e.g., McCrink et al., 2007). Empirical findings regarding operational momentum are summarized in Appendix B.

Attentional Momentum

The notion of attentional momentum suggests that a change in the direction of movement of attention across space must first overcome momentum in the current direction of movement (e.g., less time is required to detect a target [further ahead] in the direction of the current movement of attention than to detect a target [an equivalent distance] in some other direction). In a typical experiment on attentional momentum (e.g., Pratt et al., 1999),

Table 1
Analogues of Velocity and Mass in Momentum-Like Effects

Momentum-like effect	Velocity	Mass
Representational	Velocity of the target	Target size (as perceived subjective weight)
Operational[a]	Velocity along the number line	Size of the operands
Attentional[b]	Velocity of attention across space	Width of attentional focus (e.g., spotlight, zoom lens)
Behavioral	Response rate	Resistance to change of an ongoing behavior
Psychological	Reinforcement rate	Importance or value of the outcome

[a] Published reports on operational momentum have not identified the velocity and mass components of operational momentum, but based on those reports, the velocity and mass analogues listed here are hypothesized. [b] Published reports on attentional momentum have not identified the velocity and mass components of attentional momentum, but based on those reports, the velocity and mass analogous suggested here are hypothesized.

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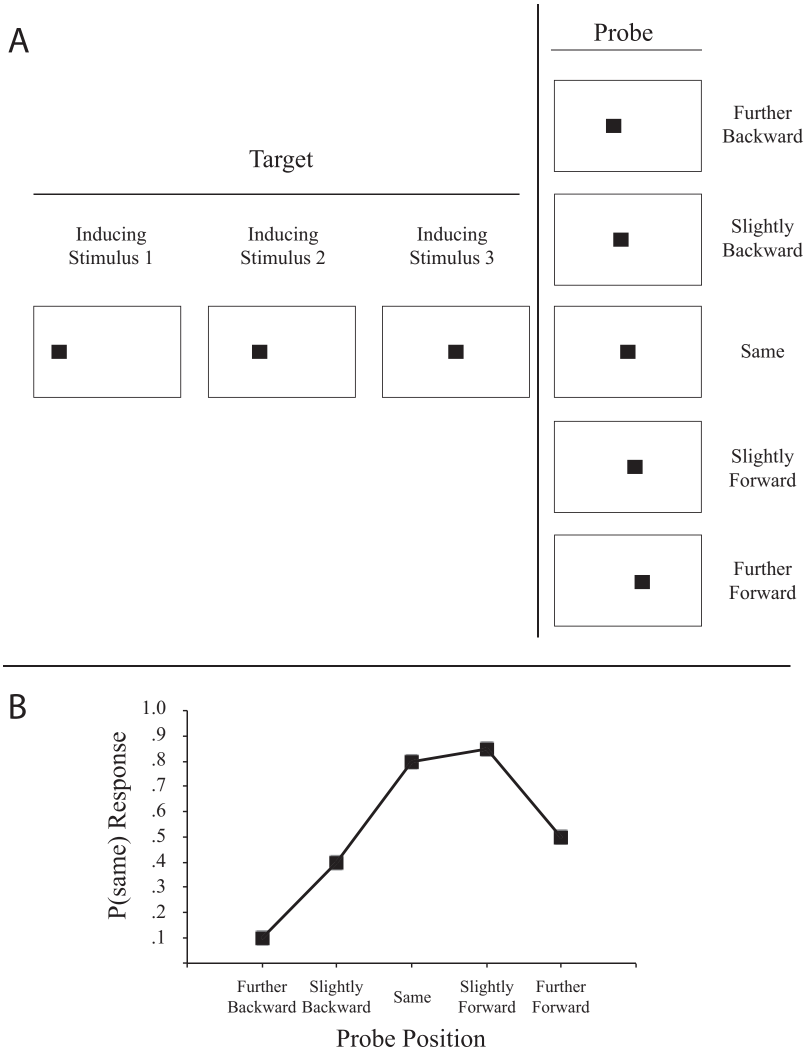

Figure 1. An illustration of a typical methodology and results for an experiment assessing representational momentum. In Panel A, the large rectangles indicate the outlines of the display, and the small black squares indicate the target (left) or probe (right). There are three consecutive appearances of inducing stimuli that comprise the target. In this example, the target exhibits implied rightward motion (typically, each inducing stimulus is presented for 250 ms, and there is a 250-ms interstimulus interval between successive inducing stimuli and between the final inducing stimulus and probe). A probe is presented, and position of the probe relative to the actual final position of the target varies across trials (five potential probe positions are shown in the column on the right). In Panel B, a hypothetical but typical distribution of *same* responses as a function of probe position is illustrated. The presence of representational momentum is indicated by the higher probability of *same* responses to probes forward of the final actual target location than to probes backward of the actual final target location. Adapted from “Forms of momentum across space: representational, operational, and attentional,” by T. L. Hubbard, 2014, *Psychonomic Bulletin & Review, 21*, p. 1373. Copyright 2014 by Psychonomic Society, Inc.

participants view a central fixation point surrounded by several equidistant locations (see Figure 2). One location is cued, and then shortly thereafter a target is presented in the cued location or in an uncued location. If a target is presented in the uncued location that is opposite to the cued location, then the time required for detection of that target is less than if a target is presented in some other uncued location, and this has been referred to as *attentional momentum* (e.g., Pratt et al., 1999). More broadly, the notion of attentional momentum suggests that the larger the change(s) in the direction of movement of attention from the cued location to a target in a different location, the longer the response time to detect that target (i.e., it takes time and effort to overcome momentum related to the initial direction of movement of attention and to then shift the movement of attention to a new direction). Attentional momentum has received the least amount of investigation of any of the momentum-like effects considered here, and empirical findings regarding attentional momentum are summarized in Appendix C.

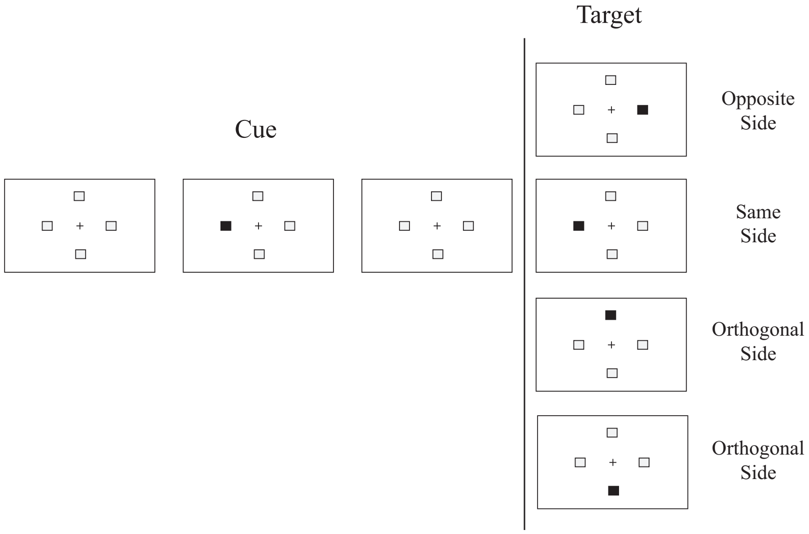

Figure 2. An illustration of a typical methodology for an experiment assessing attentional momentum. The large rectangles are the outlines of the display, the small open squares indicate potential locations where the cue and the target could appear, and the cue and the target are indicated by black squares. The fixation point is indicated by the plus sign. After participants fixate, a cue appears at one location (in this example, the left), and then vanishes. Shortly thereafter, the target appears and the location of the target relative to the location of the preceding cue varies across trials (each of the potential target locations is shown in the column on the right). The presence of attentional momentum would be indicated by a faster response time to targets that appeared in the opposite-side location than to targets that appeared in one of the orthogonal-side locations. Adapted from "Forms of momentum across space: representational, operational, and attentional," by T. L. Hubbard, 2014, *Psychonomic Bulletin & Review, 21*, p. 1388. Copyright 2014 by Psychonomic Society, Inc.

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Behavioral Momentum

Just as a physical body continues in motion until acted upon by an outside force, ongoing behavior maintained by constant reinforcement continues at a steady rate until acted upon by an external variable, and this has been referred to as *behavioral momentum* (e.g., Nevin et al., 1983). Baseline response rate is considered equivalent to initial velocity, and resistance to change is considered equivalent to mass (see Nevin, 1988, 2012); thus, behavioral momentum is the product of response rate (velocity) and resistance to change (mass). Behavioral momentum has its roots in the study of learning, and studies of behavioral momentum use methodologies, analyses, and language of learning theory. In a typical animal study of behavioral momentum, laboratory animals on multiple variable interval schedules are provided with food reinforcement (e.g., Nevin et al., 1983). Additional noncontingent food reinforcement is sometimes also delivered (e.g., Nevin, Tota, Torquato, & Shull, 1990). Resistance to extinction is higher if response rate (velocity) is higher or if additional response-independent reinforcement (increased behavioral mass) is also presented. In a typical human study of behavioral momentum, increases in reinforcement rate (tokens or rewards) of desired behaviors, and increases in compliance with instructed behaviors, increases resistance to extinction or to other disruption of the desired behavior (e.g., Parry-Cruwys, Neal, Ahearn, Wheeler, Premchander, Loeb, & Dube, 2011). Empirical findings regarding behavioral momentum are summarized in Appendix D, and reviews of behavioral momentum literature are provided in Dube, Ahearn, Lionello-DeNolf, and McIlvane (2009), Nevin and Grace (2000), and Nevin and Shahan (2011).

Psychological Momentum

Perception of whether a potential action or outcome (e.g., winning a game) can be more or less easily achieved is influenced by the outcome of previous actions or outcomes, and this has been referred to as *psychological momentum* (e.g., Iso-Ahola & Mobily, 1980; Vallerand et al., 1988). More specifically, the notion of positive psychological momentum predicts that current success or victory increases the likelihood of subsequent success or victory, and the notion of negative psychological momentum predicts that current failure or defeat increases the likelihood of subsequent failure or defeat (but see Cornelius, Silva, Conroy, & Petersen, 1997). In a typical study of psychological momentum, a participant views (e.g., Silva, Hardy, & Crace, 1988) or competes against (e.g., Shaw, Dzewaltowski, & McElroy, 1992) another individual in some task or game, and verbal reports of the momentum perceived by the participant or attributed to the other individual by the participant are collected. Other studies broadened the application of psychological momentum beyond sport or game competition to include activities such as completion of nonathletic tasks (e.g., Markman & Guenther, 2007) and financial decision making (e.g., Hendricks, Patel, & Zeckhauser, 1993). Psychological momentum is often discussed as an extrapersonal force that influences the outcomes of events, but whether such a force exists, or whether psychological momentum merely reflects people's belief in such a force, is questionable. Empirical findings regarding psychological momentum are summarized in Appendix E, and several theories of psychological momentum have been proposed (e.g., Adler, 1981; Cornelius et al., 1997; Iso-Ahola &

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Dotson, 2014; Markman & Guenther, 2007; Taylor & Demick, 1994; Vallerand et al., 1988; see also Crust & Nesti, 2006).

Part 2: Influences of Different Variables on Momentum-Like Effects

Any comparison of different momentum-like effects should consider whether each type of momentum-like effect is influenced in the same or similar ways by the same or similar variables, and Part 2 provides such a consideration. As representational momentum has received the broadest investigation of any momentum-like effect, the framework used in previous reviews of representational momentum is used here, and this framework classifies variables as reflecting characteristics of the target, display, context, or observer (Hubbard, 2005b, 2014a). It should be noted that some types of momentum-like effect have received detailed and rigorous empirical study, whereas other types of momentum-like effect have received less empirical study and are less well understood; these differences offer challenges and caveats for any consideration of potential similarities. The consideration of variables is limited to those variables that have been investigated for at least two different types of momentum-like effect, and a summary is provided in Table 2. In the absence of a model inclusive of all momentum-like effects, these comparisons are atheoretical, but can constrain hypotheses regarding properties of momentum-like effects and discussion of such a model in Parts 4 and 5, respectively. Variables examined for only one type of momentum-like effect, or that do not make clear predictions regarding other types of momentum-like effects (e.g., eye movements in representational momentum, resurgence in behavioral momentum, and self-efficacy in psychological momentum), are not considered. Similarly, if there are multiple findings regarding a given variable for one momentum-like effect, only those findings relevant to findings regarding other momentum-like effects are considered.

Target

Characteristics of the target are among the variables most extensively investigated in the literatures of several momentum-like effects. The characteristics of the target considered here include (a) velocity, (b) distance, (c) direction, (d) size, (e) identity, and (f) valence.

Velocity. As velocity is one of two variables that determine physical momentum, the momentum metaphor predicts that increases in velocity should result in increases in momentum-like effects. Representational momentum is increased with increases in target velocity (e.g., de sá Teixeira, Oliveira, & Amorim, 2010; Freyd & Finke, 1985; Hubbard, 1990; Hubbard & Bharucha, 1988). Furthermore, forward displacement is decreased if targets exhibit an irregularly changing velocity (Getzmann & Lewald, 2009), and for a constant final velocity, forward displacement is decreased if a target is consistently decelerating and increased if a target is consistently accelerating (Actis-Grosso, Bastianelli, & Stucchi, 2008; Finke, Freyd, & Shyi, 1986). In behavioral momentum literature, velocity is considered to be analogous to response rate (Nevin, 1988; Nevin et al., 1983). Withdrawing reinforcement results in a decrease in response rate equivalent to a decrease in velocity and a concomitant decrease in behavioral momentum (i.e., an increase in extinction, Nevin & Shahan, 2011). Relatedly, increases in the amount of preceding reinforcement are linked with greater positive behavioral momentum (Mace, Lalli, Shea, & Nevin, 1992; Podlesnik, Bai, & Elliffe, 2012). Velocity of change in psychological momentum appears to exhibit an initial rapid change followed by a subsequent leveling off (Briki, den Hartigh, Markman, & Gernigon, 2014). In general, faster or increasing velocity leads to larger momentum-like effects than does slower or decreasing velocity.

Distance. Distance traveled by the target does not influence representational momentum in nonclinical populations (e.g., de sá Teixeira & Oliveira, 2011), but representational momentum decreases with increases in distance traveled by the target in neglect patients (e.g., McGeorge, Beschin, & Della Sala, 2006). The amount of error in line bisection and in mental number line bisection is increased with increases in distance, and this could influence operational momentum (Longo & Lourenco, 2007). If distance is considered to include the extent of movement through time as well as the extent of movement through space, then increases in distance result in decreases in psychological momentum (cf. Eisler & Spink, 1998; Hamberger & Iso-Ahola, 2004). Increases in temporal distance appear to be (at least potentially) analogous to increases in retention interval in representational momentum and to increases in stimulus onset asynchrony (between presentation of a cue and presentation of a target) in attentional momentum, and as discussed below, increases in retention interval or in stimulus onset asynchrony can lead to decreases (after an early peak) for representational momentum (Hubbard, 2005b) and for attentional momentum (Samuel & Kat, 2003), respectively. In general, although increases in spatial distance might not influence momentum-like effects, increases in temporal distance are more likely to influence momentum-like effects, and if an effect of temporal distance occurs, momentum-like effects are generally decreased with increases in temporal distance.

Direction. Horizontal motion results in larger representational momentum than does vertical motion (Hubbard, 1990; Hubbard & Bharucha, 1988). No difference in representational momentum is usually observed between leftward and rightward motion (e.g., Cooper & Munger, 1993; Hubbard, 1990), but if a difference is observed, rightward motion usually results in larger representational momentum than does leftward motion (e.g., Halpern & Kelly, 1993). However, leftward motion along the mental number line leads to larger operational momentum than does rightward motion (Knops, Viarouge, & Dehaene, 2009; McCrink et al., 2007), and operational momentum from subtraction or addition can facilitate target detection to the left or right, respectively (Masson & Pesenti, 2014). Descending motion leads to larger forward displacement in judged location than does ascending motion (Hubbard, 1990; Hubbard & Bharucha, 1988), and this has been attributed to a combination of momentum and gravity (Hubbard, 1995c, 1997, 2005b).[1] A larger displacement for descend-

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[1] There is some inconsistency in the literature regarding use of the term “representational momentum.” Hubbard (1995c, 2005b) argued that information in addition to that arising from implied momentum can influence forward displacement, and he suggested the term “representational momentum” be limited to that aspect of displacement attributable to implied momentum of the target. In this view, a larger forward displacement for descending targets is not because of larger representational momentum per se but because of effects of representational momentum and effects of representational gravity operating in the same direction. However, some researchers prefer to use the term “representational momentum” to refer to all instances of forward displacement (e.g., Thornton & Hayes, 2004). Furthermore, some researchers use the term “representational momentum” as a description, whereas other researchers use the term as an explanation; unfortunately, which of these meanings is intended is not always clear from context.

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Table 2
Primary Influences of Different Variables on Momentum-Like Effects

	RM	OM	AM	BM	PM
Target					
Velocity	RM increases with increases with increases in velocity	?	?	BM increases with increases in velocity (response rate) and with increases in reinforcement	PM rapidly increases and then exhibits a slow leveling-off
Distance	Generally does not influence RM	OM is increased if the second operand is zero (i.e., smallest distance)	AM is larger if the cue is further from, or the target is closer to, fixation	?	?
Direction	RM is larger for horizontal than vertical motion, and larger for descending than ascending motion	OM is larger for subtraction (leftward motion) than for addition (rightward motion)	AM is larger for rightward or downward motion	BM is more likely in the current direction of behavior	Current success increases likelihood of future success; current failure increases likelihood of future failure
Size	RM occurs for changes in 2-D target size; RM for location reflects weight rather than mass	OM is not influenced by whether operands are single or double-digit	?	BM is increased with increases in behavioral mass (e.g., resistance to change)	PM is increased with increases in behavioral mass (e.g., importance of the goal)
Identity	RM is disrupted if constant identity is not maintained, and increased if motion is typical of object	OM is decreased if the operands are the same	?	?	PM is increased if the behavior or goal is considered more important
Valence	?	?	?	BM is increased with higher-quality reinforcers	Negative PM might be stronger than positive PM
Display					
Surface form	RM occurs with continuous motion, implied motion, and frozen-action photographs	OM occurs with dot clusters, Arabic numerals, and pointing to locations on a line	?	BM occurs with a variety of stimuli and reinforcers	PM occurs with a variety of stimuli and reinforcers
Retention interval	RM peaks within a few hundred milliseconds and declines	?	AM peaks within a few hundred milliseconds and then declines	BM can last for minutes, hours, days or longer	PM decreases with increases in time
Context					
Configuration	RM is increased if the surrounding context moves in the same direction or is oriented forward of the target	?	AM is exhibited for shifts that do not include changes in direction	BM is increased if a low probability request is preceded by compliance with a high probability request; BM is increased if the content contains more total reinforcement	PM is increased if a player rallies from a larger deficit, more likely in team sports than in individual sports, and difficult to reestablish after an interruption

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Table 2 (*continued*)

	RM	OM	AM	BM	PM
Expectations	RM is in the direction of expected, rather than the direction of actual, motion	?	?	BM is increased with greater reinforcement; "richer" schedules are more resistant to extinction than "leaner" schedules	PM is influenced by success or failure of one's opponent as well as one's own success or failure
Prior probability	RM is not influenced by the prior probability that a *same* response is correct	?	?	Compliance with a high-probability request increases likelihood of subsequent compliance with a low-probability request	Some studies suggest prior probability does not influence perception of the hot hand effect; other studies suggest knowledge of previous performance influences subsequent performance
Observer					
Attention	RM is increased under divided attention	Subtraction or addition facilitate target detection in the left or right visual field, respectively	Detection of a target in front of a moving object is facilitated relative to detection of a target behind the moving object	BM is larger with multiple schedules than with a single schedule	Momentum is difficult to reestablish after an interruption
Age	RM occurs in human infants, children, adults, and elderly	OM occurs in human infants and adults	?	BM occurs in human infants, children, adolescents, and adults	PM occurs in human children, adolescents and adults
Control	RM is decreased when observers control the target, and is larger in experts than in novices	?	?	?	PM is predicted to be stronger if a person has control over the action; PM is more likely in individual sports than in team sports
Goal pursuit	RM occurs in geometric stimuli if those stimuli are perceived as having a goal or social motivation	?	?	?	Effects of mindset, stop rules, and competing goals suggests PM is dependent upon belief
Feedback	RM is not eliminated by feedback	?	?	?	Some studies suggest positive feedback might increase performance; other studies suggest feedback concerning performance influences PM but not performance
Psychopathology	RM is increased by schizophrenia and decreased by mental retardation	?	?	BM is used in treatment of developmental disorder and other problem behaviors	?

Note. References are given in the main text or in the appendices. ? = there are no reported data that address this issue.

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ing motion (subtraction) for vertically oriented number lines (e.g., Ito & Hatta, 2004) could be predicted and would be consistent with the larger forward displacement for descending motion than for ascending motion in representational momentum (Hubbard, 1990, 1997). Attentional momentum is stronger for rightward or downward motion (Spalek & Hammad, 2004). Behavior consistent with positive or negative momentum is more likely than is behavior in the direction opposite to momentum (Silva et al., 1988). Negative psychological momentum might be stronger than positive psychological momentum (Gernigon, Briki, & Eykens, 2010).

Size. Representational momentum for changes in target size occurs with consistent changes in two-dimensional area (Hubbard, 1996a; Kelly & Freyd, 1987; White, Minor, Merrell, & Smith, 1993), but effects of three-dimensional mass on representational momentum are more subtle. Mass is one of two variables that determine physical momentum, and the momentum metaphor predicts that increases in mass should result in increases in momentum-like effects. Implied mass generally does not influence forward displacement along the axis of motion, but implied mass does influence displacement along the axis aligned with the direction of gravitational attraction (Hubbard, 1997; but see de sá Teixeira et al., 2010; de sá Teixeira, Oliveira, & Viegas, 2008, de sá Teixeira, Pimenta, & Raposo, 2013). Operational momentum occurs with relatively smaller (single digit) and larger (two digit) quantities (Knops et al., 2009; Lindemann & Tira, 2011). Resistance to a change in behavior is considered analogous to mass, and greater mass leads to larger behavioral momentum (Nevin, 1988). The importance or value of a behavior or outcome is considered analogous to mass, and increases in the importance or value of a behavior or outcome leads to increases in psychological momentum (Markman & Guenther, 2007). Hubbard (1997) suggested representational momentum was influenced not by objective principles regarding mass, but rather by subjective experience or consequences of mass (i.e., weight). As suggested in Part 4, an emphasis on subjective consequences is consistent with the view of mass in behavioral momentum and psychological momentum literatures.

Identity. Representational momentum is disrupted if a consistent target identity is not maintained over the course of motion (e.g., if consecutive inducing stimuli unsystematically differ in size, shape, or configuration, Kelly & Freyd, 1987), and representational momentum is increased if target identity is consistent with motion (e.g., a triangular shape is labeled "rocket" rather than "steeple," Reed & Vinson, 1996; Vinson & Reed, 2002). Judgments regarding changes in facial expressions that begin from a neutral facial expression are displaced to an even more extreme final facial expression (Yoshikawa & Sato, 2006, 2008). Indeed, to the extent that specific facial expressions are related to specific types of affect (cf. Adelmann & Zajonc, 1989), then there might also be a possibility of an affective momentum, as well. Operational momentum is decreased if the two operands are the same (Charras, Molina & Lupiáñez, 2014; also Charras, Brod, & Lupiáñez, 2012), and this effect of operand identity is consistent with effects of target identity in representational momentum. As noted above, behavioral mass is increased if the specific behavior is considered to be important or valuable, and this demonstrates an effect of target identity on psychological momentum. Furthermore, identity of the target can provide top-down (semantic) information that modulates subsequent displacement (e.g., Nagai & Yagi, 2001; Reed & Vinson, 1996) or experience of momentum (e.g., Markman & Guenther, 2007).

Valence. Psychological momentum can be considered as positive or negative. The use of the word "negative" is potentially confusing, though, as studies of representational momentum use "negative" to describe displacement in the direction opposite to target motion, and experiences of negative psychological momentum (presumably involving negative affect) and of negative reinforcement (presumably involving positive affect) are not similar. However, positive psychological momentum and negative psychological momentum each involve momentum in the direction of motion (toward success or failure, respectively), and so the possibility of positive or negative valence does not make psychological momentum inconsistent with other momentum-like effects. Higher-quality reinforcers result in a greater resistance to extinction in behavioral momentum (Ahearn, Clark, Gardenier, Chung, & Dube, 2003), and such reinforcers presumably have greater positive valence than would lower-quality reinforcers. Compliance of developmentally disabled participants with a low probability request was enhanced if reinforcer quality for previous high probability requests was increased (increasing positive valence); if multiple low probability requests were given after compliance with high probability requests, then probability of compliance declined as the number of low probability requests increased, but resistance to change across low probability requests was greater if a higher-quality reinforcer (i.e., increased positive valence) had been previously presented (Mace, Mauro, Boyajian, & Eckert, 1997). Furthermore, laboratory animals on multiple variable interval schedules are less likely to exhibit extinction after presentation of a higher-quality reinforcer (Mace et al., 1997).

Display

Relatively few characteristics of the display on momentum-like effects have been investigated for multiple types of momentum-like effect. The characteristics of the display considered here include (a) surface form and (b) retention interval.

Surface form. The format in which a stimulus is presented has been referred to as the *surface form* (analogous to the surface structure of an utterance). Representational momentum occurs with targets that exhibit discrete implied motion (see Panel A in Figure 1) or smooth continuous motion and with targets depicted in a single frozen-action photograph. The latter example is especially interesting, as a frozen-action photograph involves a single static image drawn from within a larger motion sequence (e.g., a dancer in midleap), and yet observers exhibit representational momentum that is consistent with the direction of motion suggested by the contents of the photograph (i.e., observers are more likely to accept a photograph from later in the motion sequence than from earlier in the motion sequence as being the same as the target photograph). Operational momentum occurs with (symbolic) Arabic numerals (Knops et al., 2009), (nonsymbolic) clusters of dots (Lindemann & Tira, 2011), and pointing to locations along a line (Pinhas & Fischer, 2008). Behavioral momentum and psychological momentum occur with a wide variety of stimuli, reinforcers, and behaviors. The existence of momentum-like effects with different surface forms suggests that such effects are not due solely to surface characteristics of individual stimuli or to perceptual-level processing, but instead reflect deeper principles

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(or perhaps properties of the cognitive architecture, see Hubbard, 2005b, 2006b) of cognitive or behavioral representation. This latter notion is consistent with the idea that different types of momentum-like effects might reflect similar principles or shared mechanisms.

Retention interval. Representational momentum generally increases during the first few hundred milliseconds after a target vanishes and then asymptotes or decreases with further increases in retention interval (for review, see Hubbard, 2005b). Relatedly, attentional momentum occurs if the stimulus onset asynchrony between presentation of the cue and presentation of the target is 600 ms but not if the stimulus onset asynchrony is 1,200 ms (Samuel & Kat, 2003). Increases in the temporal interval within which psychological momentum occurs might result in decreases in psychological momentum (Eisler & Spink, 1998; Hamberger & Iso-Ahola, 2004; Silva et al., 1988). Consistent with this latter finding, it has been suggested that different reinforcement rates must be compared within the same session or within alternating sessions to produce data consistent with behavioral momentum (e.g., Cohen, 1998; Cohen, Riley, & Weigle, 1993; cf. effects of latency from prior compliance with high probability requests to low probability requests, Mace, Hock, Lalli, West, Belfiore, Pinter, & Brown, 1988). However, it has also been suggested that effects of behavioral momentum can potentially last for years (cf. Nevin, 1996; Pulido & López, 2010). Effects of retention interval are not fully consistent across the different types of momentum-like effect, and this will be addressed in the discussion of time-scale in Part 5.

Context

The context refers to the physical or cognitive setting in which the target, person, or process is embedded and in which the momentum-like effect occurs. Relatively few characteristics of the context have been investigated for more than one type of momentum-like effect, and the characteristics of the context considered here include (a) configuration, (b) expectations, and (c) prior probability.[2]

Configuration. Representational momentum is increased if nearby context moves in the same direction as a target (Hubbard, 1993; Whitney & Cavanagh, 2002), a static surrounding context is oriented forward from the final orientation of a rotating target (Hubbard, 1993), or a target moves toward a landmark (Hubbard & Ruppel, 1999). Similarly, increased psychological momentum is attributed to a tennis player who comes from behind by winning four games to tie (i.e., consistently approaching a goal) than if he and his opponent alternate wins (i.e., approaching and receding from a goal) in that set (Vallerand et al., 1988; also Eisler & Spink, 1998; Miller & Weinberg, 1991). The likelihood of compliance with a request involving a low probability behavior is increased after compliance with a request involving a high probability behavior (e.g., Belfiore, Basile, & Lee, 2008; Lee, Belfiore, Scheeler, Hua, & Smith, 2004; Kelly & Holloway, 2015; Mace et al., 1988; Vostal & Lee, 2011), and latency to execution of a low probability behavior that follows a high probability behavior is faster than latency to execution of a high probability behavior that follows a low probability behavior (Lee, Belfiore, Ferko, Hua, Carranza, & Hildebrand, 2006). A preceding context containing more reinforcement leads to larger behavioral momentum (Podlesnik, Bai, & Elliffe, 2012; Podlesnik, Thrailkill, & Shahan, 2012) and larger psychological momentum (Mace et al., 1992). In general, momentum-like effects are strengthened if the configuration in which a target (behavior) is embedded contains more or stronger examples of similar continuing actions, behaviors, or outcomes.

Expectations. If a reversal in the direction of target motion is expected to occur in the very near future, representational momentum in the current direction is decreased, and at the actual moment of target reversal, representational momentum is in the direction of expected (reversed) motion (Hubbard & Bharucha, 1988; Verfaillie & d'Ydewalle, 1991). If a target is expected to stop because it is approaching a barrier (Hubbard, 1994; Hubbard & Motes, 2005) or an originally external source of motion is removed or dissipated (Hubbard, Blessum, & Ruppel, 2001; Hubbard & Ruppel, 2002), then representational momentum is decreased. Execution of a learned behavior before delivery of a reinforcer could also be viewed as a type of expectation. Learning under a schedule that provides more reinforcement per unit of time is more resistant to change than is learning under a schedule that provides less reinforcement per unit of time (e.g., Nevin et al., 1983; Podlesnik & Shahan, 2009, 2010; Podlesnik, Thrailkill, & Shahan, 2012), and greater resistance to change could be viewed as a stronger expectation of reinforcement. As noted earlier, increases in the quality of the anticipated reinforcer decreases the probability of extinction, and these findings might be viewed as expectations regarding subsequent reinforcement. Expectations arising from observation of an opponent's performance or one's own performance can trigger psychological momentum (e.g., Briki, den Hartigh et al., 2014; Briki, Doron, Markman, den Hartigh, & Gernigon, 2014; Jones & Harwood, 2008). In general, momentum-like effects are biased in ways consistent with expectations regarding subsequent actions, behaviors, or outcomes.

Prior probability. If the objective prior probability that a *same* response regarding whether a probe is at the final location of a previously viewed moving target is lower, or if participants merely believe the prior probability that a *same* response would be correct is lower, then the overall likelihood of a *same* response is decreased, but representational momentum for that target is not influenced (i.e., prior probability influences the height but not the skew of the distribution of the probabilities of *same* responses as a function of probe position, Hubbard & Lange, 2010). Gilovich, Vallone, and Tversky (1985) compared subjective perception of randomness in basketball shooting with actual performance data. The idea of a "hot hand" was not supported statistically, and examples of a perceived hot hand were not significantly different from scoring streaks predicted by a binomial model with a constant hit rate (i.e., a model that assumed no dependency between previous success and subsequent success). A similar lack of statistical differences from chance performance were found for winning streaks in major league baseball and national basketball association games (Vergin, 2000) and for distribution of service points in elite men's tennis (O'Donoghue & Brown, 2009). Such findings suggest that prior probabilities do not influence momentum-like

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[2] Hubbard (2014a) considered prior probability to be a characteristic of the display in which the target was presented. However, a broader consideration of this issue (involving additional forms of momentum-like effects) suggests that prior probability is more appropriately considered to be a characteristic of the context, and so prior probability is discussed here as a characteristic of context.

effects. Furthermore, examples in the literature usually provide additional information regarding the stimuli, and a lack of influence of prior probabilities on momentum-like effects is consistent with findings that participants are more likely to ignore prior probabilities if other information is available (e.g., Kahneman & Tversky, 1973).

The statistical findings of Gilovich et al. (1985) and others have been questioned, however. Wardrop (1995) reanalyzed the data of Gilovich et al. and reported evidence consistent with a hot hand effect if data were aggregated across players, and Jackson and Mosurski (1997) suggested Gilovich et al.'s notion of independence between consecutive performances should be abandoned. Yaari and Eisenmann (2011) found that the success of a second free throw attempt in basketball was higher when preceded by a successful first attempt than when preceded by an unsuccessful first attempt. Iso-Ahola and Dotson (2014) suggested the hot hand effect exists but is difficult to detect because it occurs relatively infrequently, and the hot hand effect has been suggested to be more frequent in individual sports than in team sports (e.g., billiards, tennis; Bar-Eli, Avugos, & Raab, 2006), if opponents are less able to use countermeasures (e.g., volleyball; Raab, Gula, & Gigerenzer, 2012), or if performance trials are uniform and participants have relatively more control (e.g., bowling; Yaari & David, 2012). Iso-Ahola and Dotson consider psychological momentum to be a psychological force rather than a statistical effect, and they suggest that enhanced performance related to psychological momentum is because of a mediating or moderating influence of psychological momentum on subsequent performance (cf. Cornelius et al., 1997; Taylor & Demick, 1994). Iso-Ahola and Dotson's discussion is consistent with the notion that psychological momentum is primarily related to the beliefs (based on performance feedback) of the individual. Indeed, the primacy of belief in a momentum-like effect on psychological momentum appears to distinguish psychological momentum from other momentum-like effects.

Observer

Characteristics of the observer include variables that have been widely investigated for some types of momentum-like effects but almost ignored for other types of momentum-like effects. The characteristics of the observer considered here include (a) attention, (b) age, (c) control, (d) goal pursuit, (e) whether the individual receives feedback, and (f) psychopathology.

Attention. If a distractor is presented at the moment when a target vanishes, then representational momentum of that target is increased (Munger & Owens, 2004), but if a distractor is presented during the retention interval between when the target vanishes and when the probe appears, then representational momentum of that target is decreased (Kerzel, 2003a). Representational momentum is larger for targets observed with divided attention than for targets observed with selective attention (e.g., Hayes & Freyd, 2002), and this is consistent with the larger behavioral momentum observed with multiple schedules than with a single schedule (e.g., Podlesnik, Thrailkill, & Shahan, 2012). Relatedly, behavioral momentum occurs with selective (Dube, McIlvane, Mazzitelli, & McNamara, 2003) and with divided (Podlesnik, Thrailkill, & Shahan, 2012) attention, but whether behavioral momentum is larger with selective attention or with divided attention has not been examined. Given that psychological momentum for a task is perceived as difficult to reestablish if a person is interrupted in that task (Markman & Guenther, 2007; see also Briki, Doron et al., 2014), it could be predicted that psychological momentum would be greater with selective attention than with divided attention. However, if controlling a target is presumed to require more attention than merely observing that target, then the decreased representational momentum exhibited if participants control a target (e.g., Jordan & Knoblich, 2004) does not appear consistent with suggestions that psychological momentum is stronger if a person is in control of the action (Vallerand et al., 1988). Relatedly, Nevin, Davison, and Shahan (2005) proposed a theory of attention based on reinforcement rate, and they suggested this theory paralleled behavioral momentum theory.

Age. The majority of studies on representational momentum and operational momentum have used adult participants, but representational momentum (Perry, Smith, & Hockema, 2008) and operational momentum (McCrink & Wynn, 2009) also appear to be exhibited by human infants. However, the extent to which representational momentum or operational momentum in infants or children differs from representational momentum or operational momentum in human adults is not clear (see Hubbard, 2014a). Studies of behavioral momentum have involved child (e.g., Lee et al., 2004; Parry-Cruwys et al., 2011), adolescent (e.g., Dube & McIlvane, 2001; Mace et al., 1997), and adult (Mace & Belfiore, 1990; Mace et al., 1988) human populations, but behavioral momentum in one age group has not been systematically compared with behavioral momentum in other age groups. Potential effects of age have not been examined for attentional momentum or psychological momentum, although such effects could be predicted.

Control. If observers control motion of a target (e.g., when the target vanishes or changes in direction or velocity of motion), representational momentum of that target is decreased or even reversed (Jordan & Knoblich, 2004; Jordan, Stork, Knuf, Kerzel, & Müsseler, 2002; see also Stork & Müsseler, 2004). However, if someone (or something) other than the observer controls the target, then observers with previous experience controlling that target exhibit larger displacement than do observers without such experience (Jordan & Hunsinger, 2008). This latter finding is consistent with findings of larger representational momentum for expert aircraft pilots (Blättler, Ferrari, Didierjean, & Marmèche, 2011) and experienced automobile drivers (Blättler, Ferrari, Didierjean, van Elslande, & Marmèche, 2010) than for nonpilots and inexperienced automobile drivers, respectively, if stimulus displays involved scenes from aircraft landings and automobile driving, respectively. The Antecedents-Consequences model of psychological momentum (Vallerand et al., 1988) suggests that spectators of athletic events, who have less control over the action, should perceive psychological momentum less strongly than do athletes in those events, who have more control over the action (Burke, Edwards, Weigand, & Weinberg, 1997); however, a comparison of psychological momentum for the same stimuli simultaneously experienced by spectators and by athletes has not been reported (cf. Briki, Doron et al., 2014).

Goal pursuit. Some accounts of behavioral momentum (Mace et al., 1997; Nevin, 1992; Nevin & Shahan, 2011) and psychological momentum (e.g., Adler, 1981; Vallerand et al., 1988) suggest that momentum-like effects are related to progress toward a goal (reinforcer). Perhaps surprisingly, motions of geo-

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metrical stimuli similar to those used in many studies of representational momentum can also be interpreted in terms of goal pursuit (e.g., attributions of social goals and attitudes to moving circles and triangles, Heider & Simmel, 1944; perception of intentionality of the initially moving object in a launching effect, Michotte, 1946/1963; larger displacement for targets moving toward a landmark than away from a landmark, Hubbard & Ruppel, 1999), and so goal pursuit might be a common feature of momentum-like effects. Such goal-directedness is obviously not present in physical momentum, and this is one way in which momentum-like effects diverge from physical momentum. Whether goal pursuit is an intrinsic aspect of momentum-like effects or separate from momentum-like effects per se is not clear, but the effects of various stop rules (e.g., Karsdorp, Nijst, Goossens, & Vlaeyen, 2010; van Wijhe, Peeters, Schaufeli, & van den Hout, 2011), mindset (e.g., Wyer, Xu, & Shen, 2012), and activation of competing goals (e.g., Fishbach, Friedman, & Kruglanski, 2003) on goal pursuit suggest continuation of behavior in psychological momentum or behavioral momentum might be more deliberate or voluntary (and more influenced by beliefs) than continuation of motion in representational momentum, operational momentum, and attentional momentum.

Feedback. Ruppel, Fleming, and Hubbard (2009) presented participants with verbal feedback regarding performance on a representational momentum task. Participants judged whether a subsequently presented probe was at the same location as the final location of a previously viewed moving target, and there were seven possible probe locations (three behind, one the same as, and three beyond the actual final target location; thus, the prior probability of a correct response was 1/7). Feedback decreased overall probability of a *same* response, but the magnitude of representational momentum was not influenced by feedback. In early studies on psychological momentum, Feather and colleagues (Feather, 1966, 1968; Feather & Saville, 1967) found that participants were more successful in solving subsequent anagrams if they had success in solving previous anagrams. In more recent studies on psychological momentum, feedback suggesting an unsuccessful performance resulted in reports of decreased positive psychological momentum but had no impact on actual subsequent performance (Kerick, Iso-Ahola, & Hatfield, 2000), and feedback suggesting a participant had lost or regained the lead in a (virtual) cycling race decreased or increased, respectively, reports of psychological momentum (Briki, den Hartigh et al., 2014; Perreault, Vallerand, Montgomery, & Provencher, 1998). Neutral or positive feedback can maintain (positive) psychological momentum (Iso-Ahola & Dotson, 2014). In general, feedback appears more effective in influencing momentum-like effects that are more cognitively penetrable to effects of beliefs (e.g., positive feedback during a period of high athletic performance would be consistent with belief in a hot hand).

Psychopathology. Patients with schizophrenia exhibit larger representational momentum than do control observers (Jarrett, Phillips, Parker, & Senior, 2002), and representational momentum of such patients is influenced by the size but not by the velocity of the target (de sá Teixeira, Pimenta, & Raposo, 2013). Patients with mental retardation exhibit smaller representational momentum than do control observers (Conners, Wyatt, & Dulaney, 1998). Patients with left hemineglect exhibit larger representational momentum than do control observers and also exhibit larger displacement for targets moving toward the left (Lenggenhager, Loetscher, Kavan, Pallich, Brodtmann, Nicholls, & Brugger, 2012), but unlike representational momentum in control participants, representational momentum in neglect patients decreases with increases in the distance traveled by the target (McGeorge et al., 2006). It could be predicted that patients with left hemineglect or schizophrenia would exhibit larger operational momentum for subtraction than would control participants; similarly, hemineglect or mental retardation could be predicted to influence effects of direction in attentional momentum. Behavioral momentum has been used in treatment of problem behavior (e.g., Ahearn et al., 2003; Belfiore, Lee, Scheeler, & Klein, 2002; Kelly & Holloway, 2015; Mace, Lalli, Shea, Lalli, West, Roberts, & Nevin, 1990; Mace, McComas, Mauro, Progar, Taylor, Ervin, & Zangrillo, 2010; Parry-Cruwys et al., 2011; Pritchard, Hoerger, Mace, Penney, & Harris, 2014), but of course, this does not suggest a causal connection between etiologies of problem behavior and behavioral momentum.

Part 3: Comparisons of Momentum-Like Effects

In Part 2, similarities of the effects of different variables on each of the momentum-like effects were examined, and in Part 3, similarities of the different types of momentum-like effects are examined. Given that studies of each momentum-like effect have often looked at different (but sometimes overlapping) sets of variables, comparisons of some momentum-like effects involve consideration of several overlapping variables or findings, whereas comparisons of other momentum-like effects involve consideration of only a few overlapping variables or findings. Part 3 summarizes these similarities for each pair of momentum-like effects (for additional discussion, see Hubbard, 2014a, in press), and the more important of these similarities will constrain hypotheses regarding the properties of momentum-like effects discussed in Part 4 and considerations for future models of momentum-like effects discussed in Part 5.

Representational Momentum and Operational Momentum

Displacement involving representational momentum (Hubbard, 1995c, 2005b) or operational momentum (Pinhas & Fischer, 2008) each reflect multiple sources of influence[3], and representational momentum and operational momentum occur with different surface forms (e.g., implied motion and smooth motion in representational momentum, Kerzel, 2003c; digits and dot clusters in operational momentum, Knops et al., 2009). Representational momentum (Kerzel, Jordan, & Müsseler, 2001) and operational momentum (Masson & Pesenti, 2014; Pinhas, Shaki, & Fischer, 2014) can facilitate target detection. Although memory for two-dimensional surface area can exhibit representational momentum

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[3] Just as Hubbard (1995c, 2005b) suggested the phrase "representational momentum" should be applied to only the component of displacement that reflected implied momentum of the target, perhaps the phrase "operational momentum" should be applied to only the component of displacement along the mental number line that reflected arithmetic operations, and the more general phrases "displacement" or "numeric displacement" should be used to refer to the difference between the actual and estimated quantities.

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(Kelly & Freyd, 1987; White et al., 1993), two-dimensional surface area or three-dimensional mass usually does not influence representational momentum for orientation or location (Cooper & Munger, 1993; Hubbard, 1997; but see de sá Teixeira et al., 2010), and the size of operands in operational momentum does not influence operational momentum (Knops et al., 2009). Representational momentum (e.g., Reed & Vinson, 1996) and operational momentum (e.g., Charras et al., 2014) are influenced by specific identity of the target (operands). Increases in attention to the target eliminate operational momentum (e.g., carrying or borrowing in addition or subtraction, respectively, Lindemann & Tira, 2011; but see Masson & Pesenti, 2014) and decrease but do not eliminate representational momentum (e.g., cueing of the final target location during target motion or during the retention interval, Hubbard, Kumar, & Carp, 2009). Representational momentum (Perry et al., 2008) and operational momentum (McCrink & Wynn, 2009) appear to occur in very young children.

Many discussions of operational momentum (e.g., Crollen & Seron, 2012; Knops et al., 2009; Longo & Lourenco, 2007; McCrink et al., 2007; Pinhas & Fischer, 2008) acknowledge similarities of operational momentum and representational momentum, and McCrink and Wynn (2009, p. 406) stated "spatial extension of attention along the number line is one example of a broader class of anticipatory phenomena known as representational momentum." Consistent with this, representational momentum (e.g., Kelly & Freyd, 1987) and operational momentum (e.g., McCrink et al., 2007) have been suggested to rely on analogue representation. Operational momentum is consistent with the nature of representational momentum described by Finke et al. (1986, p. 176), who stated "representational momentum can occur for extrapolations that have no simple analogue to the motions of physical objects. For example, implied changes in sounds, size, or color might give rise to a momentum effect if these changes can be extrapolated along some representational pathway." Finke et al. did not address numerosity or discuss the mental number line as a representational pathway, but operational momentum seems to be consistent with their description of representational momentum. Rather than simply being similar to representational momentum, operational momentum might be a special case of representational momentum (or attentional momentum) in which movement is not across physical space but is instead across the abstract space of the mental number line.

Representational Momentum and Attentional Momentum

Representational momentum (Freyd & Johnson, 1987) and attentional momentum (Samuel & Kat, 2003) decline after a few hundred milliseconds. Representational momentum (e.g., Hubbard, 1994; Reed & Vinson, 1996) and attentional momentum (e.g., Hommel, Pratt, Colzato, & Godijn, 2001) can be influenced by symbolic (e.g., verbal) information. Attentional momentum appears to be more fragile than representational momentum (e.g., attentional momentum occurs in only a minority of observers, Snyder, Schmidt, & Kingstone, 2001, 2009), and so momentum-like effects might be more robust if bound to a representation of a moving physical object than if bound to a moving fixation region or to the moving viewpoint of the self. Hubbard (1995c, 2005b, 2008; also Müsseler, Stork, & Kerzel, 2002) suggested representational momentum reflected priming of the anticipated direction of target motion by enhanced spreading activation in that direction; such directional priming could potentially account for attentional momentum, as well. Distance traveled by a target does not usually influence representational momentum in nonclinical populations (McGeorge et al., 2006; de sá Teixeira & Oliveira, 2011; for an exception, Hubbard & Ruppel, 2002), but it is not clear whether distance traveled by attention influences attentional momentum. Relatedly, increases in target eccentricity lead to slower target detection (Spalek & Hammad, 2004) and to an increase and then decrease in representational momentum (Schmiedchen, Freigang, Rübsamen, & Richter, 2013).

Spalek and Hammad (2004) suggested that movement of attention exhibits properties similar to physical momentum and that "[O]nce attention starts moving in a [specific] direction, it tends to continue moving in that direction until some force (effort) is directed against it" (p. 220). This is similar to Finke et al.'s (1986, pp. 176–177) statement "mental extrapolations, like moving physical objects, cannot be instantly halted. Instead, they continue for some time after one begins to stop them . . . people can quickly stop the mental extrapolations only by applying an opposing, internal force." As noted in Hubbard (2014a), studies of attentional momentum typically focus on differences in response times, whereas studies of representational momentum typically focus on differences in accuracy (although differences in response times were reported in early studies on representational momentum, e.g., Finke et al., 1986; Freyd & Finke, 1984). Emphases on accuracy or on response time might reflect different aspects of a single momentum associated with shifts of a (target at the) represented or attended position: Consistent with this, the phrase "representational momentum" appears more likely to be used if responses involve the judged position of a target, and the phrase "attentional momentum" appears more likely to be used if responses involve the time required for target detection (but for an exception, see Kerzel et al., 2001).

Representational Momentum and Behavioral Momentum

Representational momentum and behavioral momentum initially appear very different. The notion of representational momentum arose from studies of perception and cognition and uses methodologies and nomenclature of information-processing theory, whereas the notion of behavioral momentum arose from studies of learning and behavioral analysis and uses methodologies and nomenclature of learning theory. Articles in representational momentum literature have not addressed behavioral momentum, nor have articles in behavioral momentum literature addressed representational momentum. Even so, a few similarities can be noted. If the source of target motion is perceived to be external to the target, then representational momentum is decreased (e.g., representational momentum is smaller for a launched target with a presumed external source of motion involving impetus imparted from contact with another stimulus than for a nonlaunched target with a presumed internal source of motion; Hubbard et al., 2001; Hubbard & Ruppel, 2002), and this is consistent with the notion that internally motivated behaviors are more difficult to extinguish than are externally motivated behaviors. Larger behavioral momentum exhibited with multiple schedules (cf. Podlesnik,

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Thrailkill, & Shahan, 2012) seems consistent with larger representational momentum exhibited with divided attention (cf. Hayes & Freyd, 2002). Furthermore, withdrawing external reinforcement decreases response rate (velocity), and so behavioral momentum decreases (i.e., extinction becomes more likely); similarly, decreases in target velocity decreases representational momentum.

Nevin (1988) suggested extinction serves as a disruptor similar to a "behavioral friction," and that when this friction is increased or decreased, behavioral momentum is decreased or increased, respectively. Hubbard (1995b, 1998) demonstrated the existence of a "representational friction" (in which a target contacted a barrier or moved along the surface of a larger stationary object), and if the amount of implied friction increased or decreased, forward displacement in target location decreased or increased, respectively. With increases in behavioral friction or in representational friction, velocity (and momentum) of the behavior or target is decreased. Representational momentum peaks after just a few hundred milliseconds and then declines (e.g., Freyd & Johnson, 1987), but behavioral momentum potentially lasts for days, weeks, or even longer (e.g., Nevin, 1996; Pulido & López, 2010). However, it is not clear whether apparent behavioral momentum with longer durations results from the same mechanisms as does behavioral momentum with shorter durations (e.g., apparent behavioral momentum after longer durations might reflect a greater or additional influence of retrieval from long-term memory). Along these lines, development of behavioral momentum is dependent upon learning, whereas representational momentum is modulated but not eliminated by learning (e.g., Courtney & Hubbard, 2008; Ruppel et al., 2009) and is dissociated from explicit knowledge of the physics of moving targets (e.g., Freyd & Jones, 1994; Kozhevnikov & Hegarty, 2001). Perhaps more critically, representational momentum is not generally influenced by (implied three-dimensional) mass, but "behavioral mass" is an important determinant of behavioral momentum.

Representational Momentum and Psychological Momentum

Markman and Guenther (2007, pp. 801–802) suggest

> findings regarding representational momentum are important for PMT [psychological momentum theory] because they indicate that after viewing a target that appears to be imbued with momentum, individuals quickly develop expectations regarding the eventual displacement of the target. In kind, PMT maintains that if a target is imbued with PM, individuals will quickly develop a set of expectations regarding the displacement of that target.

Markman and Guenther also suggest (a) the "psychological mass" of a given behavior or outcome for an individual is influenced by the importance or value attributed to that behavior or outcome by that individual and (b) that psychological momentum can be influenced by naïve physical beliefs similarly to how representational momentum can be influenced by naïve physical beliefs (e.g., representational momentum [Hubbard, 2004; Hubbard et al., 2001; Kozhevnikov & Hegarty, 2001] and psychological momentum are influenced by beliefs regarding impetus). The importance of a subjective or naïve understanding of mass is consistent with Hubbard's (1997, 2005b) suggestion that the effect of mass on representational momentum reflects the subjective experience of mass (i.e., weight) rather than the objective physical principles regarding mass; thus, with representational momentum and with psychological momentum, the momentum-like effects are related to naïve beliefs and subjective experiences of a physical principle rather than to an objective physical principle per se.

The context within which a target is embedded can influence representational momentum (e.g., orientation or motion of a surrounding framework influences displacement of an embedded target, Hubbard, 1993) and psychological momentum (e.g., rallying from a large deficit to tie the score results in larger psychological momentum than if the deficit was small or the lead alternated several times, Vallerand et al., 1988). Representational momentum decreases after an early initial peak (Freyd & Johnson, 1987), and reported psychological momentum decreases as the temporal interval over which the relevant events occur is increased (Eisler & Spink, 1998; Hamberger & Iso-Ahola, 2004). Roediger (1996) considered representational momentum to be a memory illusion, and Gilovich et al. (1985) considered psychological momentum to be a cognitive illusion (but see Iso-Ahola & Dotson, 2014). Freyd (1987) suggested representational momentum reflected dynamic processes, and Briki, den Hartigh et al. (2014) and Gernigon et al. (2010) suggested their data illustrated the dynamic nature of psychological momentum (see discussion of how Freyd's description of dynamic representation might be related to behavioral momentum and psychological momentum in Hubbard, in press). However, although representational momentum clearly exists independently of beliefs about representational momentum (e.g., failure of feedback [Ruppel et al., 2009] and instruction [Courtney & Hubbard, 2008] to eliminate representation momentum), whether psychological momentum exists independently of beliefs about psychological momentum is less clear.

Operational Momentum and Attentional Momentum

Increases in the distance between operands leads to increased errors in operational momentum (Pinhas & Fischer, 2008), and increases in target eccentricity leads to slower responses in attentional momentum (Spalek & Hammad, 2004). Verbal information can eliminate operational momentum (Lindemann & Tira, 2011) and influence attentional momentum (Hommel et al., 2001). Displacement is usually larger for leftward motion than for rightward motion along the mental number line in operational momentum (McCrink et al., 2007), but displacement is larger for downward or rightward motion in attentional momentum (Spalek & Hammad, 2004). This latter difference might result from a compression of the right side of representational space (e.g., if the mental number line is logarithmically scaled, cf. Knops, Dehaene, Berteletti, & Zorzi, 2014) in numerical cognition (operational momentum) that does not occur in visual detection (attentional momentum). McCrink et al. (2007) proposed operational momentum arises from an interaction between spatial and numerical systems that results from attention moving along a mental number line (cf. Crollen & Seron, 2012); indeed, operational momentum might reflect a special case of attentional momentum in which attention is shifted not across physical space but is shifted across the more abstract space of the mental number line (see also Hubbard, 2014a). Relatedly, movements of attention along the number line and across space presumably exhibit similar velocity profiles (e.g., perhaps an initial acceleration followed by a constant velocity). Furthermore,

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operational momentum (Masson & Pesenti, 2014; Pinhas et al., 2014) and attentional momentum (Pratt et al., 1999) can facilitate target detection.

Operational Momentum and Behavioral Momentum

Nevin et al. (1983) noted (in an experiment involving multiple schedules) that the relationship between the ratio of behavioral masses and the ratio of reinforcement rates was a power function with an exponent of approximately .7, and they suggested that such a relatively low exponent was obtained because dark-key responses and extinction resulted in a decrease in behavioral mass. Alternatively, the low exponent might reflect compression of the representation of larger magnitudes, and this would be analogous to a compression of the right side of the mental number line that has been suggested by some studies of operational momentum (e.g., Longo & Lourenco, 2007). As noted earlier, operational momentum occurs with (symbolic) Arabic numerals (e.g., Knops et al., 2009), (nonsymbolic) clusters of dots (e.g., Lindemann & Tira, 2011), and pointing to locations along a line (e.g., Pinhas & Fischer, 2008), and similarly, behavioral momentum occurs with a variety of stimuli, reinforcers, and behaviors; thus, operational momentum and behavioral momentum each appear to occur with a variety of surface forms, and this is consistent with involvement of a high-level mechanism in these momentum-like effects. The sizes of the operands do not influence operational momentum (Knops et al., 2009), but the magnitude of behavioral mass does influence behavioral momentum (Markman & Guenther, 2007). Manipulation of behavioral momentum has been used to increase compliance in solving arithmetic problems; it could be interesting to examine whether increasing behavioral momentum in such circumstances would influence operational momentum.

Operational Momentum and Psychological Momentum

Operational momentum is larger with leftward motion along the mental number line (e.g., Knops et al., 2009; McCrink et al., 2007), and this is consistent with findings that changes in negative psychological momentum are often larger than changes in positive psychological momentum (cf. Gernigon et al., 2010; Stanimirovic & Hanrahan, 2004). Operational momentum occurs with Arabic numerals (e.g., Knops et al., 2009), dot clusters (e.g., Lindemann & Tira, 2011), and pointing to locations along a line (e.g., Pinhas & Fischer, 2008), and similarly, psychological momentum occurs with a variety of stimuli, reinforcers, and behaviors; thus, operational momentum and psychological momentum each appear to occur with a variety of surface forms, and this is consistent with involvement of a high-level mechanism in these momentum-like effects. As noted earlier, outcomes considered to be more important or valuable have been suggested to possess greater psychological mass (and result in larger momentum-like effects), but the sizes of the operands do not influence operational momentum; given this, it would be interesting to examine whether operational momentum is increased if the importance of providing an estimate closer to the correct answer is increased. Perhaps paradoxically, increases in the importance that an impression of numerosity closely approximates the correct answer could be predicted to increase operational momentum. The consistency of velocity of movement along the mental number line is not clear, but an initial acceleration from zero that subsequently leveled off at a constant velocity would be consistent with the pattern of velocity for increases in reported psychological momentum (e.g., Briki, den Hartigh et al., 2014).

Attentional Momentum and Behavioral Momentum

Attentional momentum is hypothesized to result from costs involved in changing the direction of movement of attention (Pratt et al., 1999), and descriptions of attentional momentum usually imply a focused or selective attention. Behavioral momentum occurs with selective (Dube et al., 2003) and divided (Podlesnik, Thrailkill, & Shahan, 2012) attention, but whether attentional momentum would increase (cf. behavioral momentum, representational momentum) or decrease (e.g., because of limited capacity) with divided attention is not clear. Attentional momentum appears to have a brief time course that lasts for only a few hundred milliseconds (Samuel & Kat, 2003), whereas behavioral momentum has been suggested to last much longer (Nevin, 1996; Pulido & López, 2010). Findings that discrimination of object shape is enhanced for stimuli located slightly in front (i.e., further in the direction of anticipated motion) of the final position of a moving target (Kerzel et al., 2001) appear to be an example of attentional momentum (as the focus of attention overshot the final position of the target), and this predicts behavioral momentum would similarly enhance (Lee et al., 2006) or increase the likelihood of (Belfiore et al., 2008; Lee et al., 2004) successful execution or recognition of a specific (and more likely) subsequent behavior. Consistent with this, if attention is considered to shift across time rather than across space, then attentional momentum (in the form of a continuation or extrapolation in the same direction) regarding a particular target is potentially consistent with behavioral momentum regarding a particular behavior.

Attentional Momentum and Psychological Momentum

Attentional momentum is larger for rightward motion and downward motion (Spalek & Hammad, 2004), and the latter is consistent with findings that changes in negative psychological momentum are often larger than changes in positive psychological momentum (Gernigon et al., 2010; Stanimirovic & Hanrahan, 2004). As noted above, attentional momentum could account for discrimination of object shape being enhanced for stimuli located slightly in front of the actual final position of a moving target (Kerzel et al., 2001), and this might predict psychological momentum would similarly enhance the execution or recognition of the most likely subsequent behavior or outcome in the predicted direction. If psychological momentum is larger for goals that are more important or that have greater value, then attentional momentum might be larger for movements involving more mass (or perhaps more correctly, attentional momentum might be larger for movements involving more weight, see Part 4). However, given that attentional momentum involves movement of the focus of attention rather than movement of an object (or representation of an object), it is not clear how mass (weight) might be manipulated in studies of attentional momentum (some speculative possibilities might involve manipulating width of the attentional "spotlight" [e.g., Cave & Bichot, 1999] or "zoom lens" [e.g., Eriksen & St. James, 1986]). The consistency of velocity of movement of atten-

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tion (in the absence of an object to which attention is bound) is not known, but an initial acceleration from zero that subsequently leveled off at a constant velocity would be consistent with the pattern of velocity for increases in reported psychological momentum (e.g., Briki, den Hartigh et al., 2014).

Behavioral Momentum and Psychological Momentum

The idea that psychological momentum is influenced by preceding events is consistent with the importance of the reinforcement schedule in behavioral momentum. Psychological momentum in a perceived hot hand effect (e.g., Iso-Ahola & Dotson, 2014) appears similar to behavioral momentum in compliance (e.g., Belfiore et al., 2008; Mace et al., 1988), in that execution of a low probability behavior is (perceived as) more likely if success (compliance) is previously established. Behavioral momentum (Nevin, 1988; Nevin & Grace, 2000) and psychological momentum (Markman & Guenther, 2007) are increased (and desired behavior is less susceptible to disruption) if reinforcement rate is increased (cf. Mace et al., 1992). Behavioral momentum (Mace et al., 1988; Parry-Cruwys et al., 2011) and psychological momentum (Iso-Ahola & Dotson, 2014; Markman & Guenther, 2007) can facilitate accomplishing desired behaviors, but behavioral momentum (Pulido & López, 2010) and psychological momentum (Gilovich et al., 1985) can result in continued use of a previously successful strategy even if such a strategy is no longer optimal or appropriate. Along the lines of the latter, behavioral momentum and psychological momentum might be especially susceptible to an individual's beliefs; indeed, it has not yet been demonstrated that psychological momentum occurs in the absence of beliefs regarding momentum (but whether laboratory animals in studies of behavioral momentum can be said to have beliefs regarding momentum might be debatable). As noted earlier, behavioral momentum might be larger for behaviors considered more important or valuable, and a similar effect of importance and value of behaviors could be predicted for psychological momentum.

Part 4: Properties of Momentum-Like Effects

Although some momentum-like effects might initially appear rather different from other momentum-like effects (cf. representational momentum and behavioral momentum), the hypothesis that different momentum-like effects reflect a similar or overlapping set of mechanisms suggests that different momentum-like effects should exhibit similar properties. Some of these properties were suggested by the comparisons discussed in Parts 2 and 3, and the most important of these are discussed in Part 4. Not every property suggested here has been studied in each momentum-like effect, but each of these properties has been observed in at least two momentum-like effects. This list is not intended to be complete, and future investigation will presumably add to, delete from, or otherwise modify the list of properties proposed here.

Dynamic Representation

Momentum-like effects involve dynamic representation. In the technical definition drawn from physics, "dynamics" involves forces, and to the extent that momentum-like effects incorporate or involve information regarding forces, then representations underlying those effects could be said to be dynamic. In fact, not only is momentum considered by physics to be a force, but other forces such as friction and gravity have also been shown to influence the anticipated action, behavior, or outcome of a target, person, or process for multiple types of momentum-like effects (Hubbard, 1995c). Previous speculation involving internalization of physical principles suggested an internalization of kinematics and geometry (e.g., Shepard, 1994; but see Hecht, 2001; Kubovy & Epstein, 2001), but studies of momentum-like effects suggest that information regarding forces is also available (Hubbard, 2006a, 2012, 2014a). In colloquial language, "dynamic" can refer to "movement" or "change." Representational momentum, operational momentum, and attentional momentum all involve movement through (some type of) space. Furthermore, momentum-like effects change over time; this typically involves a decline in magnitude (sometimes after an early peak), and the decline might occur relatively quickly (e.g., representational momentum) or relatively slowly (e.g., extinction of a well-learned behavior). Representational momentum, attentional momentum, and psychological momentum each decrease as the temporal interval within which such momentum occurs increases, and a similar decrease with increases in temporal interval could be predicted for behavioral momentum.[4] Thus, momentum-like effects appear to reflect dynamic properties of representation in both technical and colloquial senses of "dynamic" (see discussion in Hubbard, 2014a, in press).

Extrapolation of Space and Time

Related to the idea of dynamic representation is the idea that momentum-like effects involve extrapolation of space and time. Depending upon the time-scale of extrapolation, either extrapolation of space or extrapolation of time might appear more salient within the experience of the observer, with momentum-like effects at perceptual time-scales appearing to involve extrapolation primarily across space and momentum-like effects at longer time-scales appearing to involve extrapolation primarily across time (see Part 5). As noted earlier, the extent to which such extrapolation is based upon or influenced by beliefs may vary across different momentum-like effects. Given that momentum-like effects rely (at least in part) on dynamic representation, extrapolation of space and time is consistent with models of imagery based on second-order isomorphism (for discussion, see Hubbard, 2006a, 2014a) and with Freyd's (1987) suggestion that temporal information is a critical aspect of dynamic representation (see Hubbard, in press). The space within which momentum-like effects usually

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[4] Interestingly, the decline of momentum-like effects with increases in time is consistent with the naïve physics notion of impetus, and both momentum-like effects and the notion of impetus might arise from subjective experience. For example, a stationary object that receives a single push will often move a short distance and then stop, and this is consistent with a notion that the initial push imparts an impetus that dissipates with subsequent motion of the pushed object (cf. McCloskey, 1983). A theory for predicting or anticipating the behavior of the pushed object that is based on impetus is simpler (fewer parameters) and requires fewer cognitive resources than does a physically correct theory (an object in motion will continue in motion unless acted upon by an outside force [e.g., resistance from the surface the object is moving across or the medium the object is moving through]). Accordingly, a prediction based upon an impetus heuristic may be more useful than a prediction based upon the correct laws of physics (Hubbard, 2004, 2013a, 2013b).

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occur is visual physical space, but any stimulus quality that can be represented in a spatial coordinate system can potentially exhibit spatial-like displacement (e.g., operational momentum in numeric space, representational momentum in auditory frequency space). Although momentum-like effects generally involve extrapolation into the future, it is possible a similar mechanism or set of properties might involve extrapolation into the past such as that observed in the onset repulsion effect (e.g., Actis-Grosso & Stucchi, 2003; Hubbard & Courtney, 2008; Hubbard & Ruppel, 2011; Thornton, 2002).

Environmental Contingencies

Momentum-like effects are sensitive to environmental contingencies. In some types of momentum-like effects, the environmental contingencies might reflect invariant aspects of the environment (e.g., physical principles governing motion) that have been incorporated into functional properties of the cognitive architecture (e.g., Hubbard, 1995c, 1999, 2005b, 2006a). Such an incorporation is reminiscent of Gibson's (1966, 1979) notion of "invariants" that are picked up by the perceiver; interestingly, an incorporation of environmentally invariant information into mental representation offers a bridge connecting ecological approaches and representational approaches by positing that invariant information shaped the functional architecture of the representational system (or that perception is modulated by the subjective consequences of the potential actions of the observer, cf. Witt & Riley, 2014). In other types of momentum-like effect, the contingencies might reflect beliefs based on stochastic or arbitrary aspects of the environment that have been learned. This is most obviously demonstrated in the role of reinforcement in behavioral momentum (e.g., Mace et al., 2010; Nevin & Grace, 2000; Podlesnik, Bai, & Elliffe, 2012; Podlesnik, Thrailkill, & Shahan, 2012) and in psychological momentum (e.g., Mace et al., 1992; Markman & Guenther, 2007). In general, environmental contingencies involving effects of variable, arbitrary, or idiosyncratic information (e.g., word meanings, color associated with food pellet delivery), as well as environmentally invariant information (e.g., effects of momentum, gravity, friction), influence momentum-like effects.

Increases in Adaptiveness

Momentum-like effects generally increase adaptiveness of an organism to environmental contingencies. Representational momentum has been suggested to aid in compensating for neural processing times in interactions with moving targets, and this would facilitate interactions with stimuli in real-time (for discussion, see Hubbard, 2005b). Behavioral momentum and psychological momentum could be similarly adaptive in decreasing the likelihood of extinction of learned behaviors during a temporary absence of external reinforcement (e.g., as might happen with a partial reinforcement schedule or if reinforcement is otherwise delayed or inhibited). In a broad sense, and as discussed in Part 5, momentum-like effects could serve as heuristics to facilitate perception and action for the most likely actions, behaviors, or outcomes that would be subsequently encountered. Even if a specific momentum-like effect might not be clearly adaptive, such an effect is often not harmful enough to be selected against (e.g., operational momentum) and is likely to be related to or derived from a momentum-like effect that is more clearly adaptive (e.g., operational momentum might reflect representational momentum along the mental number line). As with all heuristics, the dynamic representations responsible for momentum-like effects can lead to occasional errors (e.g., an Einstellung effect, in which a previously successful strategy continues to be used even if no longer optimal or appropriate; perception of a hot hand, etc.), but the usefulness of momentum-like effects in the majority of situations that would be encountered presumably outweighs the occasional errors that can arise.

Help in Bridging a Gap

Momentum-like effects help an observer in bridging a gap. In representational momentum, the gap is generally between perception and action, and the momentum-like effect helps observers more efficiently interact with moving objects in real time. Sometimes, though, the gap that is bridged can be within the stimulus (e.g., in a natural environment, a predator or prey animal might be partially or intermittently hidden by shadows; in a laboratory study, the interstimulus interval between two inducing stimuli). In behavioral momentum or psychological momentum, the gap is between the behavior and subsequent reinforcement, and this becomes particularly important if delivery of reinforcement is intermittent (e.g., on a partial schedule) or delayed. The gap that is bridged can be short (e.g., hundreds of milliseconds for representational momentum) or long (minutes, hours, or more for behavioral momentum and psychological momentum). In a sense, the gap-filling property of momentum-like effects is similar to the idea of Pragnanz and to the Gestalt principles of perceptual grouping involving closure and good continuation, in that momentum-like effects can complete an incomplete stimulus (e.g., a partially or intermittently occluded target, a perception [behavior] and action [reinforcement] pairing, etc.) and bias perception and behavior toward the most likely stimulus action or most optimal response, respectively (see Hubbard, 2011). Relatedly, in operational momentum or in attentional momentum, the momentum-like effect results from movement of attention (across numeric space or empty space, respectively), and this movement can be considered as bridging the gap between the initially cued location (along a mental number line or in space) and a different subsequent location.

Subjective Consequences

Momentum-like effects reflect subjective consequences of environmental contingences rather than physically or statistically objective consequences of environmental contingences. Forward displacement of a horizontally moving target is generally not influenced by the implied mass of that target, but downward displacement (regardless of the direction of target motion) of a target is influenced by the implied weight of that target. Effects of mass are subjectively experienced as effects of weight, and weight is experienced in the direction of gravitational attraction and not in the direction of motion (Hubbard, 1997). Psychological mass of a behavior or outcome has been suggested to relate to the subjective importance or value of that behavior or outcome (Markman & Guenther, 2007). However, rather than "psychological mass" (and "behavioral mass"), perhaps "psychological weight" (and "behav-

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ioral weight") would be more appropriate (and more consistent with colloquial language in which an action or issue of greater importance is said to have more weight). The effect of valence in psychological momentum is related to the subjective consequences of success or failure, which often appear more salient or vivid than the objective consequences of success or failure. The increased importance of subjective consequences might also serve as a motivator to increase the likelihood of success, victory, or survival, thus further underscoring the adaptiveness of momentum-like effects. Furthermore, displacement in numeric space appears to be influenced by an apparent subjective compression of larger magnitudes and not by the objective distances between larger magnitudes.

Surface Form

Momentum-like effects occur with a wide variety of surface forms. Representational momentum is found with continuous motion, implied motion, and frozen-action stimuli. Operational momentum is found with symbolic numerals, dot clusters, and pointing to a location along a line. Behavioral momentum can be observed in a wide range of behaviors in laboratory, clinical, or everyday settings, and psychological momentum occurs for competitive or noncompetitive tasks. Occurrence of momentum-like effects with a variety of stimulus formats is evidence that such effects are not purely perceptual or low-level phenomena and suggest involvement of high-level processes. Although it is possible in principle that there are multiple momentum mechanisms for different stimulus modalities and formats, it is more parsimonious to posit a smaller number of momentum mechanisms (or even a single momentum mechanism) that operate at a high level of processing and result in momentum-like effects with different types of stimuli (cf. Hubbard, 2005b, 2006b). Freyd (1993) suggested representational momentum was dependent upon the underlying nature of the stimulus dimension rather than on the format of the target (e.g., stimuli based on continuous dimensions such as location or orientation, but not discrete dimensions such as consonant perception, would result in representational momentum). Although the discrete nature of integers might suggest that operational momentum for equations involving Arabic numerals should not occur, Knops et al. (2009) and McCrink et al. (2007) suggested the underlying representation of quantity relied on analogue (continuous) numerical magnitudes rather than on the specific format in which numeric stimuli were presented.

Occur Automatically

Momentum-like effects appear to occur automatically and do not result from explicit or deliberative prediction of future action or behavior. Explicit attention does not appear necessary for the generation of most types of momentum-like effect, although attentional momentum might be an exception to this (unless reorienting to the target occurs automatically; see Santangelo & Spence, 2008).[5] More important, the notion that momentum-like effects occur automatically does not suggest that momentum-like effects are cognitively impenetrable to explicit beliefs, knowledge, or expectations regarding the target, person, or process. Rather, the magnitude and direction of momentum-like effects can be influenced by beliefs, knowledge, and expectations of the observer (e.g., Courtney & Hubbard, 2008; Finke & Freyd, 1989; Iso-Ahola & Dotson, 2014), although such information does not necessarily influence these effects (e.g., Freyd & Jones, 1994). Intriguingly, the existence of behavioral momentum in laboratory animals, as well as possible representational momentum in laboratory animals (e.g., Neiworth & Rilling, 1987), suggests that explicit or conscious verbal processing is not necessary for generation of momentum-like effects. Indeed, in studies of representational momentum, explicit and deliberate prediction of the future location of a target resulted in backward displacement or no displacement from the actual future location rather than in forward displacement (e.g., Finke & Shyi, 1988; Munger & Minchew, 2002). Furthermore, it appears that psychological momentum experienced by spectators or participants in sporting events occurs automatically, although evidence for this latter point is only anecdotal.

Cognitive Penetrability and Cognitive Impenetrability

Momentum-like effects involve cognitively penetrable components (that are influenced by beliefs, knowledge, and expectations) and cognitively impenetrable components (that are not influenced by beliefs, knowledge, and expectations). As noted earlier, momentum-like effects at the perceptual time-scale appear less susceptible to beliefs (i.e., are relatively more cognitively impenetrable) than are momentum-like effects at longer time-scales. Although momentum-like effects might be generated automatically, the magnitude (and direction) of those effects can be modified by other information (e.g., typical direction of motion, Nagai & Yagi, 2001; expected changes in target direction, Hubbard & Bharucha, 1988). Some types of information influence momentum-like effects (e.g., oscillations in target direction, Johnston & Jones, 2006; Verfaillie & d'Ydewalle, 1991), whereas other types of information do not influence momentum-like effects (e.g., prior probabilities, Gilovich et al., 1985; Hubbard & Lange, 2010). Verbal semantic knowledge can influence momentum-like effects (e.g., rockets but not steeples are likely to ascend, Reed & Vinson, 1996; presentation of the written words "BOUNCE" or "CRASH" as cues for upcoming target behavior, Hubbard, 1994), and this demonstrates involvement of high-level processes in momentum-like effects. Representational momentum can be decreased (by influencing cognitively penetrable components) but not eliminated (because of the presence of cognitively impenetrable components) by explicit instruction or by cueing target location (Courtney & Hubbard, 2008; Hubbard et al., 2009). Similarly, beliefs regarding importance or value of a behavior or outcome modulate behavioral mass of that behavior or outcome, and hence influence behavioral momentum (Markman & Guenther, 2007).

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[5] In a potential exception, Kerzel (2003a) reported representational momentum was disrupted by presentation of a distractor during the retention interval between when the target vanished and when the probe appeared, and on this basis he claimed that attention was necessary for the maintenance of representational momentum. However, such a finding does not address representational momentum that might have been generated before the presentation of the distractor, and a more cautious conclusion would be that a distractor introduced after a target vanished can disrupt residual representational momentum. Perhaps more critically, presence of a distractor per se does not eliminate representational momentum, as a distractor presented concurrent with target motion (Hayes & Freyd, 2002) or the end of target motion (Munger & Owens, 2004) can actually increase forward displacement of the target.

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Part 5: Toward a Model of Momentum-Like Effects

Momentum-like effects unfold across space and time, and any potential model of momentum-like effects should address the spatial-temporal dynamics of such unfolding. Furthermore, any potential model of momentum-like effects should be consistent with findings regarding the effects of different variables (and different types and sources of information) on different types of momentum-like effects that were noted in Part 2, similarities and differences between different types of momentum-like effects that were noted in Part 3, and additional properties of momentum-like effects that were noted in Part 4. Suggestions regarding each of these areas are given in Part 5.

Spatial-Temporal Dynamics

The spatial-temporal dynamics of momentum-like effects are determined at least in part by characteristics of the type of information and form of representation that contribute to such effects. The characteristics considered here include (a) time-scale, (b) spatial information, (c) temporal information, and (d) properties of dynamic representation.

Time-scale. The similarities and properties noted in Parts 2, 3, and 4 suggest that different momentum-like effects are not fully independent or separate processes but instead reflect a more general phenomenon or set of mechanisms that operate over multiple time-scales. Consideration of time-scale information suggests there are two distinct groups of momentum-like effects. The first group operates on a perceptual time-scale and includes representational momentum, operational momentum, and attentional momentum. Movement of attention along an abstract mental number line (or other format of represented numerosity) or across physical space appears to have properties and consequences similar to properties and consequences of movement of an object across physical space; given this, operational momentum and attentional momentum might be special cases of a more general representational momentum. The second group operates on longer time-scales and includes behavioral momentum and psychological momentum. Reinforcement rates and environmental contingencies similarly influence behaviors and expectations regarding future performance across numerous domains; given this, psychological momentum might be a special case of a more general behavioral momentum. Furthermore, momentum-like effects in the perceptual time-scale group appear automatic, whereas momentum-like effects in the longer time-scale group appear to involve learning and perhaps volition; this difference might be related to the greater importance of valence (e.g., that might serve as a motivator, cf. Perreault et al., 1998; Stanimirovic & Hanrahan, 2004) or belief for longer time-scale momentum-like effects.

Spatial information. Differences in time-scale are consistent with a classification of different types of momentum-like effects that is based on whether a momentum-like effect is experienced primarily across space or primarily across time. All momentum-like effects involve spatial information and temporal information; however, momentum-like effects with short time-scales (i.e., representational, operational, attentional) seem to emphasize continuation across space, whereas momentum-like effects with longer time-scales (i.e., behavioral, psychological) seem to emphasize continuation across time. Consistent with this distinction, Hubbard (2014a) discussed how representational momentum, operational momentum, and attentional momentum might result from automatic processes within a spatial medium of representation. Such a medium would preserve information regarding spatial properties of stimuli and the environment (cf. Kosslyn, 1980, 1994; Shepard, 1975, 1981), and properties and consequences of transformations within that representation would parallel properties and consequences of transformations of stimuli in physical space. Even if a target representation is not initially spatial (e.g., Arabic numerals), spatial information could influence subsequent processing if the initial representation of that target subsequently accessed or activated spatial forms of representation. In general, representational momentum, operational momentum, and attentional momentum appear to reflect dynamic transformations in spatial representation, and similar shifts would occur whenever changes involved in transformation of a target or execution of a behavior or process could be mapped onto a spatial representation or coordinate system (cf. Masson & Pesenti, 2014).

Temporal information. Freyd (1987) suggested representational momentum was based on dynamic representation and that temporal information is an intrinsic and necessary aspect of dynamic representation. There are two aspects of an intrinsic representation of time: Temporal information is directional (i.e., moving in only one direction) and continuous (i.e., between any two points in time, a third point can be identified). Directionality of momentum-like effects is demonstrated in that past experience influences future behavior, whereas future behavior does not influence past experience. Continuity of momentum-like effects is demonstrated in the apparent loss of momentum-like effects after an interruption (e.g., presenting a distractor after a target has vanished, Kerzel, 2003a; calling a time-out in a basketball game, Mace et al., 1992). Finally, time is a necessary element in momentum-like effects. If temporal information is not present, then all information would presumably be represented as simultaneous (i.e., not temporally ordered). Conditioning (or attributions of causality) in behavioral momentum or psychological momentum would not be possible, as conditioned and unconditioned stimuli and responses (or cause and effect more generally) could not be clearly distinguished. Although Freyd (1987) focused on a momentum-like effect based on a perceptual time-scale, Hubbard (in press) suggested momentum-like effects with a longer time-scale also reflect intrinsic and necessary inclusion of temporal information in the representation. Indeed, temporal information appears more salient than spatial information for behavioral momentum and psychological momentum.

Properties of dynamic representation. The importance of spatial information and of temporal information in momentum-like effects is consistent with claims that such effects exhibit or are based on dynamic representation (e.g., Briki, den Hartigh et al., 2014; Freyd, 1987). Any model of momentum-like effects would have to incorporate or otherwise account for dynamic properties of representation. The clearest discussion regarding properties of dynamic representation in a momentum-like effect was given by Freyd (1987), who proposed several potential properties of dynamic representation. However, Freyd's suggestions were based solely on research in representational momentum, and contained properties that were not applicable to momentum-like effects that occur at longer time-scales (and were not applicable to dynamic representation more generally). Hubbard (in press) discussed how a subset of the properties Freyd proposed might be adapted to

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include momentum-like effects that occur at longer time-scales, and these properties are listed in Table 3. Indeed, the possibility of different time-scales in dynamic representation underscores the importance of specific temporal information (regarding the amount of change or transformation associated with a given duration) to dynamic representation that Freyd (1987) emphasized. However, and as shown in Table 3, the applicability of some of the suggested properties of dynamic representation to some types of momentum-like effect has not been explicitly addressed within the literature, and these gaps highlight potentially useful avenues of future study.

Typologies

Given that momentum-like effects involve extrapolation of an action, behavior, or outcome, it is possible that momentum-like effects in highly specific domains might reflect a more general extrapolation mechanism (i.e., be special cases of a more general

Table 3
Properties of Dynamic Representation Adapted From Freyd (1987), and How Those Properties Are Exhibited for Each Momentum-Like Effect

Dynamic property	RM	OM	AM	BM	PM
Basic phenomenon (forward displacement or continuation)	Remembered location is displaced forward in space	Dstimated quantity is displaced forward along the number line	Attention processing is facilitated for locations in the direction of motion	Learned behaviors continue until acted upon by another force	Past success more likely to lead to future success; past failure more likely to lead to future failure
Depends upon coherent direction of motion	Displacement is decreased if motion is not in a consistent direction	?	Does not occur with changes in direction of attention shift	Disrupted if contingency between response and reinforcer is disrupted	Disrupted if the task is interrupted
Does not stem from sensory processes	Is influenced by top-down information, occurs for smooth or implied motion and frozen-action photographs	Occurs for dot clusters, Arabic numerals, and subjective division of a line	Is not related to sensory characteristics	Involves learned behavior	Involves learned behavior
Is relatively unaffected by practice or error feedback	Explicit feedback and training does not eliminate forward displacement	?	?	?	Continued use of previously successful strategies even if those those strategies are no longer appropriate or optimal
A shift in memory for position (time)	Remembered location is displaced in direction of anticipated motion	Estimated sum or difference is shifted further in the direction of arithmetic operation	?	Involves anticipated (future) behavior	Involves anticipated (future) behavior
Increases with velocity	Generally increases with increases in target velocity	?	?	Increases with higher response rates	Increases with increases in reinforcement rates
Initially increases and then plateaus or decreases	Increases for first few hundred milliseconds then plateaus or decreases	?	Occurs with ISI of 600 ms but not with ISI of 1200 ms	Increases with consistent reinforcement, decreases with extinction	Stronger over (relatively) shorter temporal intervals
Attached to the represented object, not frame of reference	Displacement occurs for specific objects, not the surrounding frame or context	Reversed if larger magnitudes on left and smaller magnitudes on right	?	?	Is attributed to a specific team, individual, or activity
Dimensions of change other than rigid transformations	Displacement occurs for any dimension of continuous change	?	?	Occurs for simple (e.g., key peck) and complex (e.g., human) behavior	Involves many different types of behaviors
Differs from guessing	Explicit guessing leads to backward displacement rather than forward displacement	Guessing would lead to random distribution of errors rather than systematic bias	Guessing would not differentiate between opposite and orthogonal locations	Dependent upon conditioning and learning history	Dependent upon subjective appraisal of anticipated consequence

Note. RM = representational momentum; OM = operational momentum; AM = attentional momentum; BM = behavioral momentum; PM = psychological momentum; ? = there are no reported data that address this issue. References are given in the main text or in the appendices. The list of dynamic properties is adapted from "Dynamic Mental Representations," by J. J. Freyd, 1987, *Psychological Review, 94*, 432–433. Copyright 1987 by the American Psychological Association.

momentum-like effect). Several possibilities are shown in Figure 3. One possibility is that all momentum-like effects are independent and unrelated (Panel A). A second possibility is that momentum-like effects consist of two groups corresponding to a perceptual time-scale group and a longer time-scale group, and within each group, the different types of momentum-like effects are independent and unrelated (Panel B). A third possibility is similar to the second, but operational momentum and attentional momentum are special cases of representational momentum (and operational momentum might overlap or be a special case of attentional momentum, see Hubbard, 2014a) and psychological momentum is a special case of behavioral momentum (Panel C). A fourth possibility is similar to the third, but the perceptual time-scale and longer-time scale groups reflect a common set of mechanisms (Panel D). Given the numerous similarities that were noted earlier between representational momentum, operational momentum, and attentional momentum and between behavioral momentum and psychological momentum, the first and second possibilities can be rejected. The third possibility does not consider that all momentum-like effects might be related at the level of computational theory. This leaves the fourth possibility, which suggests that some momentum-like effects are highly related and that all momentum-like effects share a common set of mechanisms.

Computational Theory

Although differences in time-scale suggest a typology in which there are two primary groups of momentum-like effects (Panels B

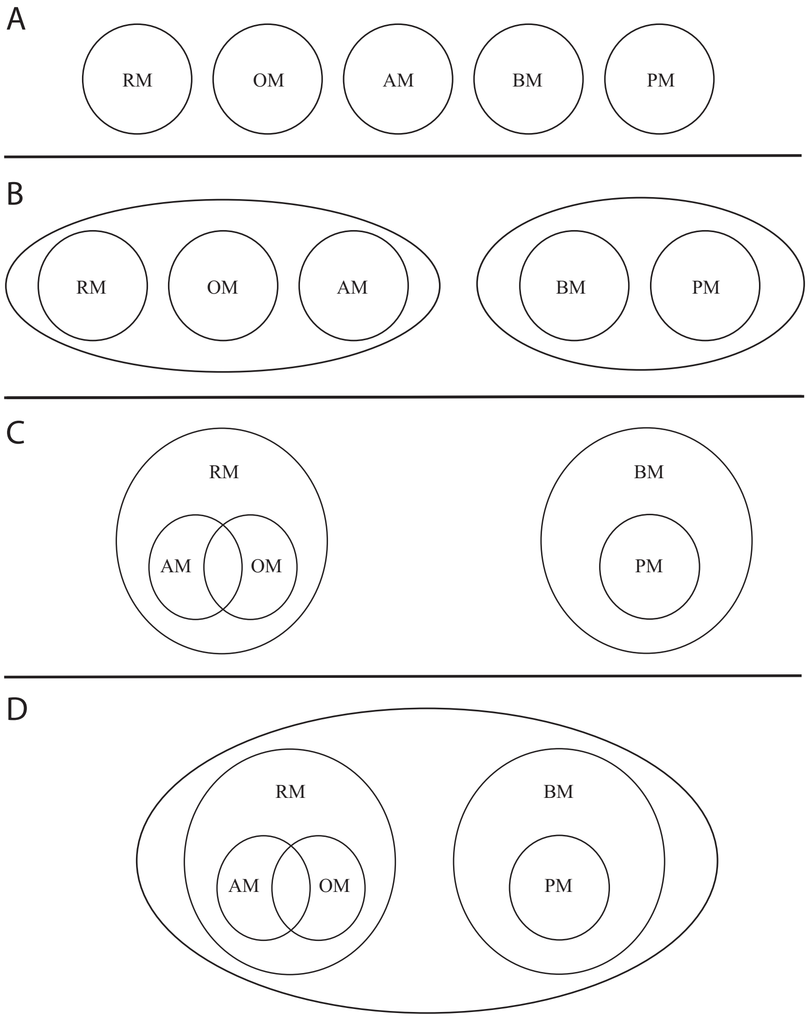

Figure 3. Possible typologies for representational momentum (RM), operational momentum (OM), attentional momentum (AM), behavioral momentum (BM), and psychological momentum (PM). In Panel A, the five momentum-like effects are separate and independent processes. In Panel B, RM, OM, and AM form one group involving perceptual time-scale momentum-like effects, and BM and PM form a second group involving longer time-scale momentum-like effects. Within each group, the different momentum-like effects are separate and independent. In Panel C, OM and AM are subsets of a more general RM, and PM is a subset of a more general BM. In Panel D, OM and AM are subsets of a more general RM, PM is a subset of a more general BM, and RM and BM are subsets of a more general extrapolation mechanism.

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and C in Figure 3), it is possible that at a higher level of explanation these two groups might each reflect a single more abstract extrapolation mechanism (Panel D in Figure 3). Given that each momentum-like effect continues or anticipates target behavior, different momentum-like effects could be viewed as similar or analogous at the level of computational theory (i.e., each momentum-like effect addresses the question of what the observer will most likely encounter in the near future). Time-scale information might be similar or analogous to a parameter passed to a more general extrapolation mechanism, and the value of the time-scale parameter would determine many of the specific characteristics of the resultant momentum-like effect. Even though different physiological mechanisms are presumably involved in different types of momentum-like effects, these differences involve the level of representation and algorithm or the level of hardware (neural) implementation rather than the level of computational theory (for discussion of these levels in general, see Marr, 1982, and as applied to representational momentum, see Hubbard, 2005b, 2006b). Although different momentum-like effects initially appear very different, this does not rule out a similar or shared mechanism; analogously, Newton's laws of motion (on which the momentum metaphor is based) demonstrate phenomena that initially appear very different (e.g., motions of Earth-bound objects and motions of celestial objects) can be governed by the same laws and principles.

An Extrapolation Mechanism

A computational theory approach suggests that models of momentum-like effects should consider a single or small number of extrapolation mechanisms. The properties of momentum-like effects noted in Part 4, and the characteristics of spatial-temporal dynamics noted in the first section of Part 5, further constrain any such models of momentum-like effects. Additional elements relevant for a model of momentum-like effects and that are considered here include (a) incorporation of a mechanism for extrapolation of momentum-like effects into the functional architecture of representation, (b) whether momentum-like effects result from beliefs or from properties of representation, (c) differences in the effects of variable experience and invariant experience, (d) differences in the effects of implicit knowledge and explicit knowledge, (e) cognitive economy, and (f) adaptive anticipation.

Functional architecture. The existence of different types of momentum-like effects suggests that such effects involve one or more extrapolation mechanisms, and the purpose of such mechanisms is to anticipate the action, behavior, or output of a target, person, or process. Different neural architectures might be implicated for different types of momentum-like effects (e.g., there is no a priori reason why extrapolation in the form of representational momentum for the position of a moving target must be instantiated in the same neural circuit as extrapolation in the form of psychological momentum for future success in an ongoing sport competition). An extrapolation mechanism might function as a subroutine into which the current action, behavior, or outcome might be entered, but such a system would not be modular (in the Fodorian sense of being informationally encapsulated), as other information possessed by an observer (e.g., semantic or other stimulus-specific information regarding the target, person, or process) could potentially influence output of the extrapolation mechanism (e.g., if a change in direction is expected, representational momentum is reduced or reversed; if a goal is highly valued, reaching that goal might result in higher psychological momentum than reaching a similarly difficult but less meaningful or less important goal). Such a subroutine would need to function rapidly and automatically. This might be most easily accomplished by incorporating such mechanisms into the functional architecture of the representational system, rather than having such functions separately computed and then applied to a representation.

Beliefs and properties. The extent to which momentum-like effects are a consequence of objective properties of the representation of an action, behavior, or process or a consequence of subjective beliefs about momentum (e.g., a belief that a momentum-like effect should occur) should be addressed by any model of momentum-like effects. Interestingly, such a difference might be related to differences in time-scale. Forms of momentum-like effect that exhibit a perceptual time-scale appear to occur regardless of the specific beliefs of the observer (e.g., representational momentum occurs regardless of an individual's knowledge regarding representational momentum [Courtney & Hubbard, 2008; Ruppel et al., 2009] and is dissociated from explicit physical knowledge [Freyd & Jones, 1994; Kozhevnikov & Hegarty, 2001]) and appear to reflect (at least in part) properties of the representation. However, it is not clear whether forms of momentum-like effect that exhibit a longer time-scale similarly involve properties of the representation or instead reflect beliefs of the observers (e.g., the hot hand effect is claimed to be veridical [e.g., Iso-Ahola & Dotson, 2014] and illusory [e.g., Gilovich et al., 1985]). Furthermore, some examples of behavioral momentum might reflect intrinsic properties of the representation (e.g., across a single session, Cohen, 1998), whereas other examples of behavioral momentum might reflect an effect of belief (e.g., across multiple years, Nevin, 1996; Pulido & Lopez, 2010). Momentum-like effects with a perceptual time-scale might primarily reflect a property of the functional architecture of representation, whereas momentum-like effects with a longer time scale might primarily reflect a belief that momentum should occur.

Hubbard (2006a; Courtney & Hubbard, 2008) proposed that displacement observed in studies of representational momentum resulted from two separate factors involving (a) a second-order isomorphism between subjective consequences of physical principles on physical objects and the mental representations of those objects that provided an automatic default displacement and (b) physical or cognitive context (including beliefs) that could modulate this default displacement. The first factor reflects a property of the functional architecture of the representation, and the second factor reflects other information about the target (including beliefs) that could modulate the output of the first factor. To the extent that operational momentum and attentional momentum are special cases of representational momentum, these two effects could be predicted to result (at least in part) from an automatic extrapolation that could be modulated but not eliminated by an observer's beliefs (although whether beliefs might influence operational momentum or attentional momentum has not been investigated). Whether behavioral momentum and psychological momentum result from a similar process in which at least one factor represents an internalization of momentum and at least one factor represents contextual information (such as provided by beliefs) that can modulate the momentum-like effect is not clear, and it is possible that behavioral

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momentum and psychological momentum might result solely from the second type of factor. Regardless, the idea of momentum is still useful in generation of hypotheses and in predicting responses across a variety of stimuli and time-scales.

Variable experience and invariant experience. Beliefs often involve perceived environmental contingencies, and as noted earlier, momentum-like effects are sensitive to environmental contingencies. Extrapolation of momentum-like effects is based in large part on expectations that are derived from experience or beliefs regarding such contingencies. If experience is invariant (e.g., effects of momentum on physical objects), momentum-like effects are more likely to be consistent with physical and statistical laws. However, if experience is variable or recent experience would constitute an outlier, momentum-like effects are more likely to be inconsistent with physical and statistical laws (e.g., perception of a hot hand); extrapolation of a momentum-like effect in such circumstances would suggest an atypical level of performance would continue, even though performance should be expected to statistically regress. To be maximally efficient (e.g., not require any additional attentional resources), it might be that information regarding invariants is incorporated into the functional architecture. In such a case, the stronger the invariance, the less likely other information is to modify the output (e.g., physical momentum is invariant, and so effects of physical momentum can be modulated but not eliminated [e.g., the direction of extrapolation, but not the presence of extrapolation, can be influenced by explicit knowledge; Finke & Freyd, 1989; Hubbard, 2005b]). In cases where there is no obvious relevant physical invariant incorporated into the functional architecture (e.g., psychological momentum in sport competition), the output might be entirely driven by belief.

Implicit knowledge and explicit knowledge. Some examples of momentum-like effects are influenced by explicit information (e.g., knowledge that an athlete rallied from a larger deficit to tie the score leads to reports of greater psychological momentum, Vallerand et al., 1988), whereas other examples of momentum-like effects are not influenced by explicit information (e.g., knowledge of Newtonian mechanical principles governing movement of objects does not influence representational momentum, Freyd & Jones, 1994; Kozhevnikov & Hegarty, 2001). Thus, any model of momentum-like effects would need to specify when explicit information would influence momentum-like effects and when explicit information would not influence momentum-like effects. The possibility that explicit knowledge influences momentum-like effects as a function of its relevance to the specific action, behavior, or outcome can be rejected, as highly relevant knowledge can influence (e.g., object identity, Reed & Vinson, 1996) or not influence (e.g., knowledge of physical principles, Freyd & Jones, 1994; Kozhevnikov & Hegarty, 2001) momentum-like effects. A second possibility is that explicit information is more likely to influence extrapolation if that information involves variable aspects rather than invariant aspects of the target, behavior, or process (e.g., in Hubbard, 2006a, a default displacement based on knowledge of [invariant] physical principles is incorporated into the functional architecture of representation, and this default displacement can be modulated by stimulus-specific [variable] explicit knowledge or expectations regarding the target).

Cognitive economy. Momentum-like effects such as representational momentum and behavioral momentum save time, effort, and cognitive resources by biasing perception and action in ways likely to be consistent with subsequent experience. In this sense, momentum-like effects are a form of heuristic, and this has at least two consequences. First, extrapolations are relatively automatic. Even so, and as noted earlier, the initial automatic extrapolation could be modulated by other (e.g., semantic) information (Hubbard, 2006a), but any such information would only modulate an existing extrapolation and would not cause an extrapolation (cf. Finke & Freyd, 1989). Second, extrapolations will not necessarily be physically or statistically correct, but will be close enough to correct to allow for an adaptive response. For example, some cases of representational momentum appear to be based on a naïve physics notion of impetus rather than on a correct understanding of momentum. Although impetus is not a valid physical principle, predictions based on an impetus notion can nonetheless yield results that are “good enough” for most purposes (e.g., a prediction based on impetus can yield a similar result but take less effort than a prediction based on consideration of multiple physical qualities such as mass, inertia, resistance, etc., see Footnote 4). Although mechanisms of momentum-like effects can produce systematic errors, momentum-like effects are not a defect of cognition. Rather, momentum-like effects are a type of heuristic that evolved to maximize useful prediction of actions, behaviors, and outcomes with minimal cost (see also Hubbard, 2004, 2005b, 2006a, 2006b, 2014a).

Adaptive anticipation. Given that momentum-like effects continue a current action, behavior, or outcome or anticipate a future action, behavior, or outcome of a target, person, or process, these effects appear related to forward models in which perception influences and is influenced by anticipated action (e.g., Desmurget & Sirigu, 2009; Mehta & Schaal, 2002). This relationship has been examined most closely for representational momentum, but such a relationship seems consistent with other momentum-like effects (e.g., attentional momentum could facilitate subsequent processing of a specific target or location further in the same direction of motion, behavioral momentum and psychological momentum could facilitate subsequent processing of the same actions or behaviors, etc.). Even if momentum-like effects do not influence perception and action directly (e.g., Cornelius et al., 1997), momentum-like effects are useful heuristics in predicting the actions, behaviors, or outcomes of targets, persons, or processes. Interestingly, the large range of time-scales for different momentum-like effects suggests that forward models operate over a larger range of time-scales than has been previously suggested. Furthermore, although the discussion here has been limited to phenomena labeled “momentum,” there are other phenomena in which momentum-like effects are exhibited and that might serve a similar function (e.g., in the flash-lag effect, a briefly presented stationary object that is aligned with a moving target is perceived as lagging behind the moving target, and one explanation for this effect involves a forward extrapolation of the location of the moving target that appears similar to representational momentum; Hubbard, 2014b).

Hubbard (1995c, 2005b, 2006a, 2006b) suggested representational momentum is an adaptation that (at least partially) compensates for neural processing times in perception. Without such an adaptation, perception of the position of a moving target would lag behind the actual position of that target, because the target would continue to move after the sensation was initiated but before that sensation reached perceptual awareness (see Figure 6 in Hubbard,

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2005b; also Nijhawan, 2008). By displacing the represented position slightly forward, the representation specifies where the target would be at that moment in real-time rather than where the target was when sensation began. As noted in Hubbard (2014a), it is not clear that operational momentum and attentional momentum are similarly adaptive, but these latter two effects might reflect generalizations of representational momentum that were not harmful enough to be selected against. Similarly, behavioral momentum and psychological momentum can be seen as adaptive if such effects facilitate recognition of or responding to subsequent stimuli in the absence of reinforcement. Thus, momentum-like effects are unified at the level of computational theory (or are derived from other momentum-like effects that are unified at the level of computational theory). Depending on the anticipated action, behavior, or outcome and on the time-scale in which anticipation would be most useful, different forms of momentum-like effect can occur, and these effects reflect a general mechanism that extrapolates current actions, behaviors, or outcomes to facilitate subsequent interactions with targets, people, or processes in the environment.

Part 6: Summary and Conclusions

Cognition and behavior exhibit biases that are consistent with future expectations regarding a target, person, or process. Some of these biases have been linked with the notion of momentum, and numerous similarities among different momentum-like effects were noted. In some cases, the similarities are fairly clear and obvious (e.g., motion through physical space and motion through numeric space in representational momentum and operational momentum, respectively), whereas in other cases, the similarities are more speculative (e.g., velocity profiles of motion of attention along the mental number line or across space in operational momentum or attentional momentum, respectively, and the velocity profile for increases in psychological momentum). The number of apparent similarities of different momentum-like effects suggests there might be connections between such effects. Given that each momentum-like effect involves the most likely action, behavior, or outcome of a target, person, or process, it is likely that such effects decrease the cognitive effort involved in perceiving or interacting with such stimuli by anticipating (and thus facilitating perception of) the most likely action, behavior, or outcome. Thus, momentum-like effects will usually have an adaptive or facilitative effect on subsequent perception and action, and so momentum-like effects can be considered as examples of a new heuristic, a momentum heuristic, that has wide-ranging applicability across multiple types of stimuli and multiple time-scales. In general, different varieties of momentum-like effects provide useful strategies for successfully interacting with a wide range of stimuli in everyday experience.

Initial consideration of the similarities of different momentum-like effects suggested two main groups: a perceptual time-scale group including representational momentum, operational momentum, and attentional momentum, and a longer time-scale group including behavioral momentum and psychological momentum. Further consideration suggested all momentum-like effects might be unified at the level of computational theory and exhibit a number of properties including (a) dynamic representation; (b) extrapolation of actions, behaviors, or outcomes in space and in time; (c) sensitivity to variable or invariant environmental contingencies; (d) increases in adaptiveness; (e) bridging a gap within the stimulus or between the stimulus and response; (f) emphasis on the subjective aspects of environmental contingencies rather than on objective aspects of those contingencies; (g) insensitivity to irrelevant stimulus-specific characteristics (e.g., surface form); (h) automatic application of the mechanism responsible for momentum-like effects; and (i) containing cognitively penetrable components and cognitively impenetrable components. Relatedly, momentum-like effects involve a combination of properties of the representation and beliefs of the observer, with beliefs possibly having a more prominent (even exclusive) role in momentum-like effects on longer time-scales. Although it is possible there are separate momentum mechanisms in each modality and for each stimulus quality that exhibits a momentum-like effect, it is more parsimonious to posit a more general and abstract high-level mechanism (or small number of such mechanisms) that extrapolates and anticipates actions, behaviors, and outcomes regardless of stimulus-specific surface form and modality.

A number of constraints and issues that would need to be addressed in any potential model of momentum-like effects were discussed. Constraints and issues related to spatial and temporal dynamics include the (a) time-scale of the momentum-like effect, (b) role of spatial information, including whether momentum-like effects result from properties of spatial representation, (c) role of temporal information, including whether temporal information is intrinsic and necessary in dynamic representation, and (d) general properties of dynamic representation. Relatedly, such a model would need to specify the relationships between different types of momentum-like effects and address aspects of the extrapolation mechanism including the extent to which (a) dynamic information is incorporated into the functional architecture of representation, (b) momentum-like effects reflect substrate-independent beliefs of the observer or intrinsic properties of the representation, (c) variable experience and invariant experience influence momentum-like effects, (d) implicit knowledge and explicit knowledge influence momentum-like effects, (e) momentum-like effects result in cognitive economy by acting as heuristics to predict subsequent actions, behaviors, and outcomes, and (f) momentum-like effects lead to adaptive anticipation of subsequent actions, behaviors, and outcomes. An approach at the computational theory level was sketched here, but more detailed research remains to be done (e.g., in the cells containing a "?" in Tables 2 and 3), especially at the level of algorithm and representation and at the level of hardware (neural) implementation.

The idea of momentum provides a metaphor that (a) motivates empirical research and theoretical development regarding momentum-like effects and (b) offers a potentially unifying framework for data across multiple domains of perception, activity, and experience. Although there are clear limitations of a literal momentum metaphor (e.g., regarding representational momentum, see Hubbard, 2010; regarding psychological momentum, see Iso-Ahola & Dotson, 2014), an abstract and generalized form of momentum in which the potentially subsequent action, behavior, or outcome of a target, person, or process is represented as continuing (i.e., is extrapolated) in the direction of the current action, behavior, or outcome (cf. Finke et al., 1986; Freyd, 1987) could be highly useful (e.g., representational momentum helps compensate for delays in perception because of neural processing times, Hubbard, 2005b, 2006a, 2006b; behavioral momentum maintains the strength of a learned behavior in the absence of reinforcement, Nevin, 1988; Nevin & Grace, 2000), even if in some circumstances such a metaphor or heuristic leads to expec-

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tations inconsistent with physical or statistical laws. The similarities of momentum-like effects discussed here suggest different momentum-like effects might involve similar or overlapping dynamic processes that help an individual respond more adaptively to environmental stimuli (or can be seen as consequences of such processes, e.g., operational momentum might be a consequence of a more generalized representational momentum). In this sense, the different types of momentum-like effects are among the most useful, general, and ubiquitous adaptations in cognition and behavior.

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(*Appendices follow*)

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Appendix A

Variables That Influence Representational Momentum

Variable	RM	Primary sources
Velocity	RM is increased with increases in velocity	de sá Teixeira, Hecht, & Oliveira (2013); Freyd & Finke (1985); Hubbard (1990); Hubbard & Bharucha (1988)
	RM is decreased if a target is decelerating and increased if a target is accelerating	Actis-Grosso et al. (2008); Finke et al. (1986)
	RM is decreased with an irregular velocity	Getzmann & Lewald (2009)
	Does not influence RM in schizophrenia patients	de sá Teixeira, Pimenta, & Raposo (2013)
	Larger RM of facial expression with faster changes in expression	Yoshikawa and Sato (2008)
Direction	Descending motion leads to larger RM than ascending motion	Hubbard (1990, 1997); Hubbard & Bharucha (1988)
	Horizontal motion leads to larger RM than vertical motion	Hubbard (1990); Hubbard & Bharucha (1988)
	No differences in RM between rightward motion or leftward motion	Hubbard (1990); Hubbard & Bharucha (1988); Cooper & Munger (1993)
	Rightward motion leads to larger RM than leftward motion	Halpern & Kelly (1993)
	No differences in RM between clockwise motion and counterclockwise motion	Freyd & Finke (1984); Kelly & Freyd (1987)
	RM for clockwise motion is larger than for counterclockwise motion	Joordens et al. (2004)
	RM is larger for targets that rotate downward than for targets that rotate upward	Munger & Owens (2004)
	RM is larger with receding motion than with approaching motion	Hubbard (1996a); Nagai et al. (2002)
	Rotation around an axis that corresponds to viewer or object coordinate system results in larger RM	Munger et al. (1999a,199b)
	RM is reversed if a change in direction (oscillation) is expected	Hubbard & Bharucha (1988); Johnston & Jones (2006), Verfaillie & d'Ydewalle (1991)
	RM of auditory targets is increased or decreased as targets move toward or away from midline, respectively	Schmiedchen et al. (2013)
Distance	Distance traveled by target does not influence RM	de sá Teixeira & Oliveira (2011)
	RM is decreased with distance traveled by target in neglect patients	McGeorge et al. (2006)
Eccentricity	RM of visual or auditory targets increases with increases in eccentricity to paralateral, and then decreases with further increases in eccentricity	Schmiedchen et al. (2012, 2013)
Blurriness	RM is increased with increases in target blurriness	Fu et al. (2001)
Shape	RM is decreased if target shape varies inconsistently	Kelly & Freyd (1987)
	RM for rotating targets is not influenced by implied drag resulting from shape	Cooper & Munger (1993)
	RM for linearly moving targets is decreased with increased in implied drag resulting from shape	Hubbard (2005a)
	RM can be enhanced if an object moves in the direction in which it appears to point	Nagai & Yagi (2001)
	RM in shape occurs for consistent change in shape	Foster & Gravano (1982); Kelly & Freyd (1987)
Mass	Mass does not influence RM along the axis of motion	Cooper & Munger (1993); Hubbard (1997)
	Implied mass influences RM along the axis aligned with gravity	Hubbard (1997, 1998)
	Smaller ascending targets exhibit less RM than larger ascending targets	Kozhevnikov & Hegarty (2001)
	Effects of target mass and target velocity are additive	de sá Teixeira et al. (2008, 2010)
	RM is increased with increases in mass in schizophrenia patients	de sá Teixeira, Pimenta, & Raposo (2013)
Identity	RM is increased if target identity is consistent with target motion	Reed & Vinson (1996); Vinson & Reed (2002)
Animacy	No difference in RM between drawings of animate or inanimate stimuli	Freyd & Pantzer (1995); Halpern & Kelly, (1993)

(*Appendices continue*)

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Appendix A (*continued*)

Variable	RM	Primary sources
Human face	Facial expressions are displaced to more extreme expressions	Uono et al. (2010); Yoshikawa & Sato (2006, 2008)
	RM is increased if emotional expression was inconsistent with approach and gaze-led face orientation	Hudson & Jellema (2011)
	RM is decreased if gaze direction lags face orientation	Hudson et al. (2009)
Human body	Apparent RM for sign-language stimuli is because of biomechanical constraints rather than learned motor patterns	Wilson et al. (2010)
	Observers anticipate future postures of actors	Verfaillie & Daems (2002)
	RM for position of point-light characters in a spatial layout or with a static view	Jarraya et al. (2005)
Modality	RM occurs for changes in auditory pitch	Freyd et al. (1990); Hubbard (1995a); Kelly & Freyd (1987)
	RM in direction of oscillating pitch motion	Johnston & Jones (2006)
	RM occurs for moving sound sources	Getzmann et al. (2004)
	RM occurs at the end but not in the middle of a sound source trajectory	Getzmann (2005); Getzmann & Lewald (2007, 2009)
	Auditory pitch is displaced consistent with an effect of gravity	Hubbard & Ruppel (2013a)
	RM occurs for haptic opening and closing	Brouwer et al. (2005)
Surface form	RM is larger with continuous motion than with implied motion	Faust (1990)
	RM is larger with implied motion than with continuous motion	Kerzel (2003c)
	No difference between RM with implied motion or with continuous motion	Hubbard (1995a); Poljansek (2002)
	RM occurs with static stimuli that suggest motion (i.e., frozen-action photographs)	Freyd & Pantzer (1995); Freyd et al. (1988); Futterweit & Beilin (1994); Hubbard & Blessum (2001)
	Perceived motion in direction opposite to depicted motion in habituated frozen-action photographs	Pavan et al. (2011); Winawer et al. (2008).
Latency to vanish	RM is decreased with increases in latency between a button press to make the target vanish and when the target vanishes	Jordan et al. (2002)
Retention interval	RM increases during the first 300 ms	de sá Teixeira, Hecht, & Oliveira (2013); Freyd & Finke (1985); Freyd & Johnson (1987); Kerzel (2000)
	RM with 125 and 500 ms retention intervals do not differ	Halpern & Kelly (1993)
	RM decreases after approximately 500 ms	Freyd & Johnson (1987)
	Downward displacement of horizontally moving targets increases for at least 1200 ms	de sá Teixeira, Hecht, & Oliveira (2013)
Prior probabilities	Decreased likelihood of a *same* response, but no change in RM, with decreases in prior probabilities	Hubbard & Lange (2010)
Brightness	RM does not occur for changes in luminance	Brehaut & Tipper (1996); Favretto (2002)
	RM for location is increased with increased target luminance	Hubbard & Ruppel (2014)
Contrast	RM is increased with decreases in target luminance	Maus & Nijhawan (2006, 2009)
	RM is increased with increases in contrast of background and target	Hubbard & Ruppel (2014)
	RM for location influenced by final, not initial or mean, contrast	Hubbard & Ruppel (2014)
Shading	Shading provides depth information that influences RM	Hidaka et al. (2009)
Response measure	RM is larger with cursor-positioning or reaching than with probe judgment	Kerzel (2003c); Kerzel & Gegenfurtner (2003)
	RM is larger with reaching when the participants' hands are not visible than when the participants' hands are visible or with cursor-positioning	Ashida (2004)
	RM is larger with reaching than with cursor-positioning (trackball)	Motes et al. (2008)
Error feedback	RM is impervious to error feedback	Finke & Freyd (1985)

(*Appendices continue*)

Appendix A (*continued*)

Variable	RM	Primary sources
	Error feedback decreases probability of a *same* response, but not RM	Ruppel et al. (2009)
Crossmodal information	Visual information influences auditory RM	Hubbard & Courtney (2010); Schmiedchen et al. (2012)
	Auditory information influences visual RM	Chien et al. (2013); Schmiedchen et al. (2012); Teramoto et al. (2010)
	Auditory information influences visual representational gravity	Hubbard & Courtney (2010)
Nontarget stimuli	Stationary object near the final location of the target is displaced in direction of target motion	Hubbard (2008)
	Illusory motion induced by nontarget stimuli does not influence RM	Hubbard & Ruppel (2013b); Nagai & Saiki (2005)
	Illusory motion induced by nontarget stimulus does influence RM	Hubbard et al. (2005); Taya & Miura (2010)
Landmarks	RM is increased if the target moves toward a stationary landmark and decreased if the target moves away from a stationary landmark	Hubbard & Ruppel (1999)
	A target moving parallel to a larger surface is displaced toward that surface	Hubbard (1995b, 1998)
	A stationary target is displaced toward a landmark	Hubbard & Ruppel (2000)
Height in picture plane	RM is decreased with increases in height in the picture plane for ascending or descending targets	Hubbard (2001)
Surrounding context	Orientation or movement of a surrounding or nearby stimulus influences RM	Gray & Thornton (2001); Hubbard (1993); Whitney & Cavanagh (2002)
	Motion of the self through a scene results in RM for the viewpoint	Munger et al. (2005); Thornton & Hayes, (2004)
Scenes	RM and boundary extension are separate	DeLucia & Maldia (2006); Munger et al. (2005)
	RM and boundary extension share many properties and reflect expectations	Hubbard et al. (2010)
	RM is not related to learning of spatial layout	Brown & Munger (2010); Munger et al. (2006)
	RM is larger if viewpoint rotates than if viewpoint rotates and translates	Brown & Munger (2010)
Expectations of future motion	If a reversal of target direction is expected, RM is backward (in the expected direction)	Hubbard (1994); Hubbard & Bharucha, (1988); Johnston & Jones (2006), Verfaillie & d'Ydewalle (1991)
	If a target is expected to stop as it approaches a barrier, RM is reduced or eliminated	Hubbard (1994); Hubbard & Motes (2005)
Attribution of the source of motion	RM is decreased if target motion is attributed to contact from another stimulus	Hubbard et al. (2001); Hubbard & Favretto (2003); Hubbard & Ruppel, (2002)
Causality	RM is decreased for launched targets relative to several types of control targets	Choi & Scholl (2006); Hubbard et al. (2001); Hubbard & Ruppel (2002)
	RM for launched targets does not differ from RM for passed targets	Choi & Scholl (2006)
	RM is larger for entrained targets than for launched targets	Hubbard (2013a)
	RM is decreased if an intermediary bridges the gap between the launcher and the target	Hubbard & Favretto (2003)
	Increases in launcher size lead to larger target RM and higher ratings of how far the target would travel	de sá Teixeira et al. (2008)
Gravity	Horizontally moving targets also displaced downward	Hubbard (1990, 1997); Hubbard & Bharucha (1988); Motes et al. (2008)
	Descending targets exhibit greater forward displacement than ascending targets	Hubbard (1990, 1997); Hubbard & Bharucha (1988)
	Momentum and gravity effects are statistically independent	Motes et al. (2008)
	RM for horizontal motion is larger if shading suggests downward motion	Taya & Miura (2010)
	No effect of implied gravity for neglect patients	Lenggenhager et al. (2012)
	Effects of implied gravity increase with increases in retention interval (at least to 1200 ms)	de sá Teixeira, Hecht, & Oliveira (2013)

(*Appendices continue*)

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Appendix A (*continued*)

Variable	RM	Primary sources
	Auditory pitch is displaced consistent with an effect of gravity	Hubbard & Ruppel (2013a)
	Effects of implied gravity occur with stationary targets	Freyd et al. (1988); Hubbard & Ruppel (2000)
	Effects of body axis and external gravity axis combine	de sá Teixeira (2014)
Friction	RM for rotating targets is not influenced by implied drag	Cooper & Munger (1993)
	RM for linear motion is decreased if a target slides along a surface	Hubbard (1995b, 1998)
	RM for linear motion is increased if a target appears more streamlined	Hubbard (2005a); Nagai & Yagi (2001)
	RM is not decreased if a horizontally moving target slides along a surface and is not visually tracked	Kerzel (2002)
Centripetal force	A target following a circular orbit is displaced along the tangent (RM) and inward (consistent with centripetal force)	Hubbard (1996b)
	Inward displacement of a target following a circular path is increased if the target is not visually tracked	Kerzel (2003b)
Age	No difference in RM between third-grade, fifth grade, and adult participants who view frozen-action photographs	Futterweit & Beilin (1994)
	First-grade participants exhibit larger RM than fourth-grade or adult participants	Hubbard et al. (1999)
	Apparent RM in children 24–32 months old	Perry et al. (2008)
	RM is decreased in children 5–9 years old who had been born preterm	Taylor & Jakobson (2010)
	RM is decreased in adults older than 65	Piotrowski & Jakobson (2011)
Attention	RM is increased if attention is divided	Hayes & Freyd (2002); Joordens et al. (2004)
	RM is increased if a distractor is presented when the target vanishes	Munger & Owens (2004)
	RM is decreased or eliminated if a distractor is presented during the retention interval	Kerzel (2003a)
	RM is decreased but not eliminated if final target position is cued	Hubbard et al. (2009)
Eye movements	RM for smoothly moving targets is decreased if participants fixate away from the target	Kerzel (2000, 2002, 2003b), Kerzel et al. (2001), de sá Teixeira, Hecht, & Oliviera (2013)
	RM for implied motion targets is not influenced by whether participants fixate away from the target	Kerzel (2003a)
	Oculomotor behavior does not influence RM with reaching when the hands are not visible, but RM is decreased when reaching and the hands are visible or with cursor-positioning	Ashida (2004)
	Oculomotor behavior does not influence RM of a moving sound source	Getzmann (2005)
	RM for smooth motion occurs even if participants could not visually track the target	Getzmann & Lewald (2009); Schmiedchen et al. (2013); Teramoto et al. (2010)
	RM occurs in schizophrenia patients (who presumably exhibit eye tracking dysfunction)	de sá Teixeira, Pimenta, & Raposo (2013); Jarrett et al. (2002)
Expertise	Experts exhibit larger RM for targets in their domain of expertise	Blättler et al. (2010, 2011); Nakamoto et al. (2015)
Knowledge about RM	Instructing participants about RM and asking them to compensate for RM decreases but does not eliminate RM	Courtney & Hubbard (2008)
Action plans	RM is decreased if action plans are engaged (i.e., if participants trigger target disappearance)	Jordan et al. (2002); Jordan & Knoblich (2004)
	Previous experience controlling the target increases RM	Jordan & Hunsinger (2008)
	RM is decreased if participants control the target	Jordan & Knoblich (2004); Stork & Müsseler (2004)
Psychopathology	A strong trend for patients with schizophrenia to exhibit larger RM than control participants	Jarrett et al. (2002)
	Mentally challenged patients exhibit smaller RM than control participants	Conners et al. (1998)
	Neglect patients exhibit decreases in RM with longer target trajectories	McGeorge et al. (2006)

(*Appendices continue*)

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Appendix A (*continued*)

Variable	RM	Primary sources
	Neglect patients exhibit larger RM than controls	Lenggenhager et al. (2012)
	RM in schizophrenia patients is influenced by target size but not target velocity	de sá Teixeira, Pimenta, & Raposo (2013)
Physiology	RM is larger for stimuli in the left visual field	Halpern & Kelly (1993); White et al. (1993)
	Greater cortical activity in right parietal area when participants exhibit RM	Amorim et al. (2000)
	Presentation of frozen-action photographs actives motion area V5/MT	Kourtzi & Kanwisher (2000); Senior et al. (2000)
	TMS of V5/MT eliminates RM	Senior et al. (2002)
	Prefrontal and anterior cingulate may be activated in RM	Rao et al. (2004)
	RM for facial expressions is decreased in patients with Autism Spectrum Disorder	Uono et al. (2010, 2014)

Appendix B

Variables That Influence Operational Momentum

Variable	OM	Primary sources
Surface form	OM occurs with Arabic numerals	Crollen & Seron (2012); Knops et al. (2009); Longo & Lourenco (2007); Pinhas & Fischer (2008)
	OM occurs with pointing to a location on a line	Pinhas & Fischer (2008); Pinhas et al. (2014)
	OM occurs with clusters of dots	Crollen & Seron (2012); Knops et al. (2009); Lindemann & Tira (2011)
Direction	OM is larger for subtraction than for addition	Knops et al. (2009); Lindemann & Tira (2011); McCrink et al. (2007)
Size	OM occurs with single-digit and with multi-digit numerals	Knops et al. (2009); Lindemann & Tira (2011); McCrink et al. (2007)
	OM does not occur if a "carry" or "borrow" operation is required	Lindemann & Tira (2011)
	OM occurs if a "carry" or "borrow" operation is required	Masson & Pesenti (2014)
	Size of the operands does not influence OM	Knops et al. (2009)
	OM might reflect logarithmic representation of larger magnitude	Knops et al. (2014); McCrink et al. (2007)
Distance	Amount of error in line bisection and mental number bisection increased with distance	Longo & Lourenco (2007)
Symmetry	Different-operand addition problems results in OM, same-operand addition result in underestimation	Charras et al. (2012, 2014)
	Zero as second operand leads to larger OM	Pinhas & Fischer (2008)
Age	9-month old infants appear to exhibit OM	McCrink & Wynn (2009)
	Children 6-7 years old might exhibit an "inverse OM"	Knops et al. (2013)
	OM occurs in adults	Knops et al. (2009); McCrink et al. (2007); Pinhas & Fischer (2008)
Attention	Overestimation not due to just attentional shifts along the mental number line	Crollen & Seron (2012)
	Arithmetic operations induce spatial shifts of attention to the left or right	Masson & Pesenti (2014); Pinhas et al. (2014)

(*Appendices continue*)

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Appendix C

Variables That Influence Attentional Momentum

Variable	AM	Primary sources
Direction	AM is in the direction away from a cued location	Pratt et al. (1999)
	AM occurs only if the cued location is on the left	Snyder et al. (2001, 2009)
	AM is increased for rightward and downward motion	Spalek & Hammad (2004)
Distance	AM is increased if the cue is farther from fixation or the target is closer to fixation	Spalek & Hammad (2004)
	Responses in the cued hemifield are slower than responses in the opposite hemifield	Spalek & Hammad (2004)
Cue duration	Manipulating cue duration eliminated AM	Snyder et al. (2001)
Stimulus onset asynchrony	AM appears with SOAs of 400–600 ms, but not 1,200 ms	Samuel & Kat (2003); Samuel & Weiner (2001)
Attention	Discrimination is enhanced for targets in front of the final moving target position	Kerzel et al. (2001)
Eye movements	AM is not related to voluntary saccades	Machado & Rafal (2004); Sumner (2006)
	AM is not related to cortical mechanisms of oculomotor behavior	Sumner (2006)

Appendix D

Variables That Influence Behavioral Momentum

Variable	BM	Primary sources
Extinction	Extinction is decreased with increases in BM	Nevin (1988); Nevin et al. (1983); Nevin & Shahan (2011)
	Resistance to change is decreased less by changes in response-reinforcer relationships than stimulus-reinforcer relationships	Podlesnik & Shahan (2008)
	Response-independent reinforcement decreases rate of extinction	Mace et al. (1988, 2010); Nevin et al. (1990); Nevin & Shahan (2011); Podlesnik, Bai, & Elliffe (2012)
	Training of alternative response is more effective if initial training is in a different context than the target response	Podlesnik, Bai, & Elliffe (2012)
	Extinction is decreased if discrete stimuli are presented in an earlier component of a multiple schedule	Podlesnik & Fleet (2014)
Type of response	Variation in responding is preferred to fixed (repetitive) responding	Arantes et al. (2012)
Rate of reinforcement	Higher rates of reinforcement lead to larger BM	Mace et al. (1992); Nevin (1988); Nevin & Shahan (2011); Podlesnik & Shahan (2009, 2010); Roane et al. (2004)
	Continuous reinforcement results in greater BM than does partial reinforcement	Nevin (1988, 2012); Nevin & Grace (2000)
Attention	BM occurs under divided attention	Podlesnik, Thrailkill, & Shahan (2012)
Latency	Latency between completion of a high probability request and a low probability request is shorter than latency between a low probability request and a high probability request	Lee et al. (2006)
Clinical setting	BM theory is useful in clinical settings	Dube et al. (2003, 2009); Mace et al. (1988, 1990); Parry-Cruwys et al. (2011); Pritchard et al. (2014)

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Appendix D (*continued*)

Variable	BM	Primary sources
	Likelihood of compliance to a low probability request is increased after successful compliance to a high probability request	Belfiore et al. (2002, 2008); Kelly & Holloway (2015); Lee (2006); Mace et al. (1988); Mace & Belfiore (1990); Vostal & Lee (2011)
Academic productivity	High probability sequences can increase subsequent productivity	Belfiore et al. (2008); Burns et al. (2009); Lee et al., (2004)
Reinforcement schedule	Reduction in dark-key periods were less for shorter intervals of prior reinforcement	Nevin et al. (1983)
	Resistance to change is related to multiple schedules but not to simple schedules	Cohen (1998); Cohen et al. (1993)
	"Richer" schedules are more resistant to change than are "leaner" schedules	Cohen (1998); Nevin (1992); Nevin et al. (1983); Podlesnik & Shahan (2009, 2010); Podlesnik, Bai, & Elliffe (2012); Podlesnik, Thrailkill, & Shahan (2012); Sweeney & Shahan (2013b)
	BM may account for historical events such as initiation of war and military strategies	Nevin (1996); Pulido & López (2010)
Reinforcer quality	BM is increased with higher quality reinforcers.	Mace et al. (1997)
	Increased resistance to change following access to preferred stimuli	Ahearn et al. (2003)
Resurgence	An additional source of reinforcement increases BM and chance of resurgence	Shahan & Sweeney (2011)
	Resurgence can be strengthened during extinction if alternative reinforcer is introduced	Podlesnik & Shahan (2009, 2010); Pritchard et al. (2014)
	Increased exposure to extinction can reduce resurgence	Sweeney & Shahan (2013a)
	High rates of alternative reinforcement result in more resurgence when discontinued	Pritchard et al. (2014); Sweeney & Shahan (2013b)
	Adding and removing alternative reinforcement influences resurgence, but adding and removing the alternative stimulus does not influence resurgence	Podlesnik & Kelley (2014)

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Appendix E

Variables That Influence Psychological Momentum

Variable	PM	Primary sources
Valence	Positive PM or negative PM are more likely than positive inhibition or negative facilitation	Silva et al. (1988)
	Negative facilitation is more likely than positive inhibition	Perreault et al. (1998); Stanimirovic & Hanrahan (2004)
Direction	Positive PM increases linearly, negative PM increases nonlinearly	Gernigon et al. (2010)
	Positive PM and negative PM each increase rapidly before becoming more stable	Briki, de Hartigh, Markman, & Gernigon (2014)
Duration	PM is relatively short-lived	Hamberger & Iso-Ahola (2004)
Mass	Greater importance or value can increase BM and PM	Markman & Guenther (2007)
	More difficult to reestablish PM after an interruption	Markman & Guenther (2007)
	Interrupting positive PM decreased PM, interrupting negative PM increased PM	Briki, Doron, Markman, den Hartigh, & Gernigon (2014)
Probability	Chance variation is often misinterpreted as PM	Gilovich et al. (1985); O'Donoghue & Brown (2009); Vergin (2000)
Cohesion	Teams with higher cohesion are more likely to experience positive PM	Eisler & Spink (1998)
Configuration	PM is increased if a player rallies or comes from behind	Eisler & Spink (1998); Miller & Weinberg (1991); Vallerand et al. (1988)
Gender	Male athletes experience more PM and rally more often than female athletes	Iso-Ahola & Mobily (1980); Mace et al. (1992); Roane et al. (2004); Weinberg et al. (1981, 1983)
	PM is not influenced by gender	Silva et al. (1988); Smisson et al. (2007)
Affect	PM is independent of affect in novice performers	Kerick et al. (2000)
	Affect is part of the causal chain of PM	Taylor & Demick (1994)
Self-efficacy	Self-efficacy and PM are different constructs that rely on different antecedents	Shaw et al. (1992)
Control	Individuals with more control over an outcome experience greater PM than observers	Vallerand et al. (1988); Yaari & David (2012)
	Virtual actors exhibit greater negative PM than observers	Briki, Doron, Markman, den Hartigh, & Gernigon (2014)
	Perceived hot hand is more likely in individual sports than in team sports	Bar-Eli et al. (2006)
	Negative correlation between external control and PM; no correlation between internal or god-mediated control and PM	Smisson et al. (2007)
History	Individuals who win the first game or set or more likely to win the second game or set	Adams (1995); Iso-Ahola & Blanchard (1986); Iso-Ahola & Mobily (1980); Silva et al. (1988)
	Individuals who win the first game or set are not more likely to win the second game or set	Silva et al. (1992); Stanimirovic & Hanrahan (2004)
	Individuals who make the first free throw are more likely to make the second free throw	Yaari & Eisenmann (2011)
Trigger	Spectators have low agreement on events that trigger PM	Burke et al. (1997)
	High confidence can trigger or result from positive PM, low confidence can trigger or result from negative PM	Jones & Harwood (2008); Taylor & Demick (1994); Vallerand et al. (1988)
	Opponent body language and performance can trigger PM	Jones & Harwood (2008)
	PM is a consequence of past behavior and does not influence future performance	Cornelius et al. (1997)

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