Psychological Bulletin
2012, Vol. 138, No. 4, 616–623


0033-2909/12/$12.00 DOI: 10.1037/a0028539

COMMENT

# Visual Perception of Force: Comment on White (2012)

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White (2012) proposed that kinematic features in a visual percept are matched to stored representations containing information regarding forces (based on prior haptic experience) and that information in the matched, stored representations regarding forces is then incorporated into visual perception. Although some elements of White's (2012) account appear consistent with previous findings and theories, other elements do not appear consistent with previous findings and theories or are in need of clarification. Some of the latter elements include the (a) differences between perception and impression (representation of force; relationship of force and resistance; role and necessity of stored representations and of concurrent simulation; roles of rules, cues, and heuristics), (b) characteristics of object motion and human movement (whether motion is internally generated or externally generated and whether motion is biological or nonbiological; generalization of human action and the extent to which perceived force depends upon similarity of object movement to human patterns of movement), (c) related perceptual and cognitive phenomena (representational momentum, imagery, psychophysics of force perception, perception of causality), and (d) scope and limitations of White's account (attributions of intentionality, falsifiability).

*Keywords:* perception of force, perception of causality, phenomenal causality, causal impression, perception of motion

White (2012) suggested that the visual perception of a stimulus does not initially contain information regarding the forces acting on that stimulus but that information regarding forces is subsequently added to the visual perception to create a visual impression of force. The addition of information regarding forces involves a matching of kinematic features in the visual percept with kinematic features in a simulation that is based on stored representations and that occurs concurrently with visual perception. The concurrent simulation contains information (based on previous mechanoreceptor experience) regarding forces, and if there is a matching of kinematic features, then information regarding forces related to the matched kinematic features is incorporated into the visual percept to create a visual impression of force. However, there are several issues in White's (2012) account that require clarification. Some of these issues involve the empirical consistency of White's (2012) account with existing findings and theories, and other issues involve the definition and use of terminology. These empirical and semantic issues involve the (a) nature of and differences between perception and impression, (b) characteristics of generation and generalization of object motion and human movements, respectively, (c) relationship of White's (2012) account to related perceptual and cognitive phenomena, and (d) scope and limitations of White's (2012) account.

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## Perception and Impression

Issues in this section involve the representation of force (and differences between perception and impression); the relationship of force and resistance; the role of stored representations and concurrent simulation; and the roles of rules, cues, and heuristics.

### Representation of Force

White (2012) suggested "referring to 'perceived forces' would carry an implication that the forces are actually out there and perceived as they are, but the evidence indicates that the forces people report perceiving do not correspond closely to forces in the world" (p. 590). However, there are numerous examples within psychological science in which we speak of the "perception" of something that is not actually in the world. Just as it is possible to speak of "perceived illusory contours" or "perceived negative afterimages," it is possible to speak of "perceived forces," even if those perceived forces do not closely correspond to forces in the world (e.g., see Arnheim, 1974, 1988). Similarly, just as we do not "have impressions" of various illusions, but we perceive illusions, accounts of causality such as Michotte's (1946/1963) suggest that we do not "have impressions" of causality, we perceive causality. If we perceive causality, then it is plausible that we might also be able to perceive forces related to causality. White (2012) rejected any possibility of visually perceiving forces (e.g., "information about forces is not available to the visual system," p. 592), but he suggested that we can have visual impressions of force (e.g., "we do not just perceive the kinematics of tennis games; we have visual impressions of the effort exerted by the players," p. 593); even so, White's (2012) distinction became blurred when he stated that he would use "*perceptual impression* (often shortened to *impression*) to refer to forces and causality as perceived" (p. 590, emphasis in original).

It has long been known that perception involves a combination of top-down and bottom-up influences (e.g., Gestalt perceptual grouping, apparent motion), but in White's (2012) separation of perception and impression, perception appears to involve only bottom-up information, and impression appears to involve both top-down information and bottom-up information. However, bottom-up processes and information can contribute to perception of illusions (e.g., the path of apparent motion is represented in visual cortical area V1, regardless of whether the inducing stimuli are attended, Muckli, Kohler, Kriegeskorte, & Singer, 2005; contrast illusions such as Mach bands involve reflexive mechanisms "outside the realm of cognition," Purves, Williams, Nundy, & Lotto, 2004, p. 146). Given that illusions by definition involve the perception of information not in the objective physical stimulus, findings that bottom-up processes contribute to perception of illusions suggest that bottom-up processes might contribute to the perception of forces even if those perceived forces do not correspond closely to forces in the world. Curiously, although White (2012) rejected theories such as Leyton's (1992) that suggest that forces are visually perceived, the incorporation of force information into perception that White (2012) proposed is surprisingly similar to the perception of the causal history of forces that have acted on an object that Leyton proposed (e.g., last sentence of White's, 2012, Footnote 4).

## Force and Resistance

A key element of White's (2012) account is that observers are more aware of the force they exert upon an object than of the force an object exerts upon them. The framework of Desmurget and Sirigu (2009) that White discusses in addressing this asymmetry involves practiced actions on objects. With such actions and objects, monitoring for deviations from the expected force occurs outside of awareness, and only in cases of deviation from the expected force does awareness of the force exerted by an object on the observer occur. Given this, might a lack of awareness of forces exerted on us by objects in practiced actions reflect automaticity and overlearned behavior? If so, then it is not that we are incapable of perceiving forces; rather, due to our experience with that specific action or object, such information has dropped out of awareness (as would occur with any well-learned task). A lack of awareness of forces acting on us might reflect habituation of mechanoreceptor input in that or a similar circumstance rather than processes specific to the perception of force or forward models. This seems consistent with White's (2012) claim, "during normal, learned actions on objects with no more than minimal, low-level correction . . . any representation of the inertial force exerted by the object on them is not heeded" (p. 591). Interestingly, White (2012) referred to the resistance exerted by an object on a hand as "inertial force," but it is not clear this is consistent with his treatment of force and resistance as separate qualities.

The physics of moving objects does not distinguish between force and resistance, but White (2012; also White, 2009, 2011) suggested that moving objects are perceived as exerting force and that stationary objects are perceived as exerting resistance. White (2009, 2011) maintained that a general asymmetry existed in which ratings of the amount of force exerted by object A in the launching effect, entraining effect, and enforced disintegration are greater than ratings of the amount of resistance exerted by object B in those effects. Given that an asymmetry in the perception of force and a failure of perception to reflect Newton's third law are key elements of White's (2012) account, it is important to consider the relationship of force and resistance. If resistance is equivalent to force, then the asymmetry in the perception of force (and differences from Newton's third law) might be less than the ratings of perceived force or the ratings of perceived resistance considered separately suggest. White (2009) found that (a) ratings of the perceived force of object A in a launching effect were larger than ratings of the perceived resistance of object B and that (b) ratings of the perceived force of object B differed from ratings of the perceived resistance of object B. How these differences are consistent with White's (2012) suggestion that objects are perceived as exerting force if sensory feedback is discrepant with the forward model but as exerting resistance if sensory feedback is not discrepant with the forward model, and with whether the object is in motion or stationary, is not clear.

## Stored Representations and Concurrent Simulation

Another key element of White's (2012) account is the presence of stored representations that contain information regarding force and resistance. White (2012) suggested that "kinematic properties of interactions between objects visually perceived are matched to stored representations that specify forces, and the information about forces is then incorporated in the perceptual interpretation of the interaction" (p. 594). In White's (2012) account, information regarding force is initially contained within "a simulation that runs concurrently with the perception of the stimulus" (p. 610), and this information is then incorporated ("injected," p. 608) into a visual percept. Having stored representations contribute information about forces is very different from a direct perception of causality such as that suggested by Michotte (1946/1963) and that White (2012) otherwise seemed to accept. Furthermore, it is not clear how causality could be visually perceived if the forces involved in causality could not be visually perceived. Also, it is not clear how the incorporation of force information from stored representations into visual perceptions differs from the filling in of other types of information by relevant schemata. In one sense, White's (2012) account appears to be a special case of a general class of feature matching or schema models of pattern recognition in which kinematic features in a stimulus are matched to previously perceived kinematic features associated with information regarding forces and resistance.

## Rules, Cues, and Heuristics

White (2012) asserted that "it is worth noting what is not part of this account. . . . There are no inductive rules, cues, or heuristics" (p. 605). White (2012) also downplayed the importance of specific features in his statement that "no particular cue or combination of cues is necessary to the identification process. Matching depends simply on the degree of resemblance" (p. 601). However, not depending upon a particular cue or combination of cues is different from not depending upon any cue at all. If kinematic features of a perceived stimulus are matched with kinematic features in stored representations to determine which stored representations describe forces operative on that stimulus, then would not such kinematic features be functioning as cues (cf. White's, 2012, Footnote 11)? Also, White's (2012) suggestion that "information about forces and causality in the stored representation supports inferences about forces and causality in the observed action" (p. 595) seems inconsistent with his claim that there are no inductive rules in his account (unless perhaps "inference" is intended in the sense used by Helmholtz, 1867/1910, and Rock, 1985, or such rules refer not to perception but to subsequent conceptualization). Other authors (e.g., Kahneman & Tversky, 1982) consider simulation to be a heuristic, and this seems inconsistent with White's (2012) claim that there were no heuristics in his account.[1]

## Object Motion and Human Movement

Issues in this section involve the characteristics of object motion and human movement, the source and type of motion (e.g., whether internally generated or externally generated, whether biological or nonbiological), and whether the perception (impression) of force in a nonhuman object depends upon a generalization from human patterns of movement.

### Source and Type of Motion

Despite White's (2012) suggestion that we use acquired knowledge to resist attributing the motion of nonbiological stimuli to "goals, intentions, beliefs, and desires" (p. 597) and his discussion of this issue in his Footnote 7, White's (2012) account sometimes appears to have equated the perception of internally generated motion with the perception of biologically caused motion and to have equated the perception of externally generated motion with the perception of nonbiologically caused motion. White (2012) stated, "objects in motion (motion not perceived as externally caused) tend to be interpreted as engaged in biological motion" (p. 600) and "I have reviewed evidence that object motions not perceived as externally caused tend to be perceived as biologically plausible, which means in effect that they are perceptually interpreted as instances of biologically caused motion" (p. 607). Although White (2012) used the qualifier of "tend" in these statements, it is not clear when or how often such tendencies would not occur. A weaker statement, "if motion is not perceived as externally caused, the extent to which it is perceived as internally caused and as involving exertion depends upon whether its kinematic properties can be matched to the kinematic properties of human actions" (White, 2012, p. 599), postulated that a similarity to human movement is sufficient for the incorporation of force information for internally generated motion without suggesting that the perception of such motion is biased toward the perception of a biological cause.

White (2012) claimed that it is not biologically possible to go immediately from being stationary to moving at a constant high velocity, whereas a launched object (whose motion is externally generated) can appear to go immediately from being stationary to moving at a constant high velocity (as a result of collision). Given his earlier statement that motion that is not perceived as externally caused (i.e., motion perceived as internally generated) is more likely to be interpreted as biologically caused, White's (2012) account implies that stimuli involving internally generated motion are constrained by the limitations of biologically caused motion and that stimuli involving externally generated motion are not constrained by the limitations of biologically caused motion. However, whether motion conforms to such a biological constraint seems at most a heuristic for determining whether motion is biologically caused, as a similar constraint holds for at least some motion that is not biologically caused (e.g., in normal operation, an automobile cannot go immediately from being stationary to moving at a high velocity without a period of acceleration, and the normal motion of an automobile would presumably not be perceived as biologically caused or as dependent on contact from other objects).

White (2012) claimed that biologically caused motion conforms to the two-thirds power law, and although this might be true, this does not entail that the two-thirds power law is unique to biologically caused motion. For example, when operating an automobile, a driver typically decelerates when navigating high-curvature regions and accelerates on low-curvature regions, and so the two-thirds power law might also hold for machines with internal engines. Just as the inability to go immediately from being stationary to moving at a constant high velocity might be a heuristic (rather than a defining characteristic) for determining whether motion is biologically caused, so too compliance with the two-thirds power law might be a heuristic (rather than a defining characteristic) for determining whether motion is biologically caused. Although White (2012) suggested that stimuli deviating from the two-thirds power law might result in inaccurate perception, such stimuli do not result in inaccurate perception any more than representational momentum (discussed below) results in inaccurate perception. In both cases, constraints regarding a regularity of motion influence the processing of motion information, and the exploitation of such regularity (in whatever form) would be adaptive. It is only if highly artificial stimuli are presented that such perception appears to be in error.[2]

[1] Although White's (2012) use of the term "simulation" is consistent with that in Barsalou (2008), as White (2012) pointed out in his Footnote 11, there are a number of differences in his use of the term "simulation" and other uses of "simulation" in the literature. Indeed, given these differences, what White describes as "simulation" might better be described as feature matching (in which the kinematic features of a stimulus are matched to information in long-term memory). White's (2012) "matching" and "injection" procedures are similar to the "matching" and "execute" procedures in SOAR (Newell, 1990) and procedures in ACT–R (Anderson, 1993). Perhaps of greater concern, it is not clear why simulation is necessary in White's (2012) account and why the matching of the kinematic features of a stimulus to information in memory could not proceed directly without creating a separate and concurrent simulation.

[2] Computer-animated stimuli typically used in studies of representational momentum do not possess mass, so such stimuli would not experience the effects of momentum, gravity, or friction. However, findings from such studies show that observers' memory for the location of such stimuli is displaced in ways consistent with the effects of momentum, gravity, and friction. Hubbard (2005, 2006) argued that such displacement demonstrated the robustness of these types of displacement and that information involving subjective aspects of such invariant physical principles was internalized in the functional architecture of the representational system. A similar argument might be made regarding the two-thirds power law: Given that the two-thirds power law seems to be an invariant description of at least some types of motion, it might have become internalized in the representational system, and the "inaccurate perception" if a stimulus deviated from the two-thirds power law demonstrates the robustness of internalization of the two-thirds power law.

## Generalizing Human Action

One of the primary claims in White's (2012) account is that humans do not perceive force or exertion in the movements of nonhuman stimuli that deviate significantly from patterns of human movement. For example, based on Morewedge, Preston, and Wegner (2007), White (2012) suggested we would not perceive the exertion of a fly whose wings beat hundreds of times per second because such motion is at a tempo much faster than the tempo of human movements. Similarly, White (2012) claimed, "motion of snakes and snails could be perceived as biological in the sense of animacy, but visual impressions of force and the exertion of effort are likely to be minimal or absent" (p. 599) and "some forms of motion evoke no impression of force because they cannot be matched to any humanly possible action; I would suggest a snake moving over smooth ground as an example" (p. 599). However, White (2012) also claimed, "an object does not have to look like a human being or any part of a human being for it to be perceived as exerting force" (p. 595). White's (2012) account is consistent with findings that a humanly possible movement made by a stimulus that does not look like a human leads to an impression of force (e.g., a geometric shape can "push" another geometric shape just as a human can "push" an object) and suggests that a movement that is not humanly possible does not lead to an impression of force.

White's (2012) suggestion that we could not perceive force or exertion in movements of a snake, fly, or snail that are not consistent with humanly possible movement is reminiscent of Nagel's (1974) "What Is It Like to Be a Bat?" article. Although White (2012) did not discuss Nagel's article, he nonetheless appeared to propose an extension of Nagel's argument. In brief, Nagel suggested that because humans do not have the same sensory apparati as bats and do not navigate by echolocation, humans could not imagine the subjective experience of what it is like to be a bat. Humans could of course have an abstract understanding of how bat echolocation operated, but because humans lacked the sensory apparati for echolocation that bats possess, we could not imagine the subjective experience of what it was like to actually be a bat that navigated by echolocation. Nagel focused on the importance of similarities in perceptual apparati, but White (2012) extended Nagel's argument to include the importance of similarities in skeleto-muscular structures and in the types and tempi of motor action. White's (2012) extension of Nagel's argument suggested that because humans do not possess the skeleto-muscular apparatus to move like a snake, humans could not imagine the experience of moving like a snake, and therefore, humans do not perceive force or exertion in the visual movement of a snake.

White (2012) suggested that even though we do not perceive force in the movements of a snake, fly, or snail, we do perceive force in the turning wheel of a train. Given that White (2012) linked the visual perception of force with a similarity to human patterns of movement, this suggestion is surprising; I can make a part of my body approximate moving like a snake more easily than I can make a part of my body approximate rotating continuously in a single direction like a wheel. White (2012) suggested that the perception of force in a rotating wheel arises from the experience of interacting with wheels (e.g., pedaling a bicycle); however, a turning wheel of a train (or bicycle) exhibits continuous rotation in a single direction relative to the rest of the locomotive (or bicyclist), but no part of the human skeleto-muscular structure can exhibit continuous rotation in a single direction relative to the remainder of the body (nor would continuous rotation of the entire body necessarily provide the relevant movement pattern or information[3]). Curiously, the limitation of whether the visual perception (or impression) of force occurs in this example is not whether a movement pattern is humanly possible but whether an observer has interacted with similar stimuli.[4] The perception of force in a turning wheel seems inconsistent with the claim that force (or exertion) is only perceived if the movement of a stimulus is similar to a humanly possible movement; indeed, based solely on movement patterns of the human body, we should not be able to perceive force in a rotating wheel.

## Related Perceptual and Cognitive Phenomena

Issues in this section involve representational momentum (and the possibility of an impetus heuristic), imagery involving mental rotation or concurrent with perception, the psychophysics of perceived force, and the perception of causality involving stimuli other than those in a launching effect.

### Representational Momentum

The remembered location of a moving target is often displaced (i.e., shifted away) from the actual location of that target and in the direction of anticipated motion, and this is referred to as *representational momentum* (for review, Hubbard, 2005). Some theories of representational momentum attribute this displacement to a form of internalization or belief regarding the dynamics and forces that would act on a physical object (for review, Hubbard, 2010), and so, consideration of representational momentum is relevant to questions regarding the representation or perception of force. Find-

[3] An anonymous reviewer suggested that it might be possible to learn about the force of a turning wheel by lying on the ground and rolling down a hill. However, rolling down a hill does not fit with White's (2012) suggestions regarding the role of mechanoreceptor feedback in learning about force (p. 591), as rolling down a hill does not (a) guide or involve decisions about the amount of force to be exerted, (b) allow for detection of errors and higher level correction based on deeper processing, or (c) involve the monitoring of sensory feedback regarding inertial load or force load on the body. The role of mechanoreceptor feedback in learning about force in White's (2012) account appears to limit such learning to cases in which there is active manipulation of an external object in which force is exerted (i.e., involving "violations of expectations about the inertial load of objects, and the unpredictable force loads generated on the body by active objects or by objects being acted on by external forces," p. 591), but no such active manipulation or exertion is involved in passively rolling down a hill. If it is possible to learn about the force of a turning wheel from lying on the ground and passively rolling down a hill, then some mechanism other than that suggested by White (2012) would appear to be required.

[4] It should also be noted that some limitations on the perception of force might reflect a lack of sensory sensitivity rather than dissimilarity to human patterns of movement or a lack of interaction with similar stimuli. For example, White (2012) suggested that we do not perceive force or exertion in the motion of a fly's wings or a snail's crawl because those actions occur outside the tempo of human action, but it is possible we do not perceive force or exertion in motion of a fly's wings or a snail's crawl because those actions are above and below, respectively, our threshold for detection of motion.

ings regarding high-level or top-down influences on representational momentum are consistent with White's (2012) suggestion that information regarding forces can be added to visual perception. However, in some theories of representational momentum, at least a portion of the dynamic information relevant to representational momentum is not injected into the percept from a high-level mechanism or concurrent simulation separate from that percept, but is instead an intrinsic and necessary part of the representation (Freyd, 1987) and is incorporated directly into the functional architecture of the representational system (Hubbard, 2006).[5] It is possible that information regarding the forces operative on a stimulus might be similarly incorporated into the functional architecture of the representational system, thus eliminating the need for concurrent simulation and the matching of kinematic features.

White (2012) stated, "if an object is to be intercepted accurately, the action must be aimed not at the object's current location (or its location as perceived) but at where the object will be when the interception occurs" (p. 604). Hubbard (2005, 2006) presented the same argument and suggested that representational momentum bridged the gap between perception and action and helped compensate for delays due to neural processing times. Such a bridging would have to take account of forces acting on an object and on the observer. Unlike White (2012), though, Hubbard (2005) suggested that the representation of such forces did not have to be objectively correct but only had to be close enough to objectively correct to allow the observer to successfully interact with the object. For example, Hubbard, Blessum, and Ruppel (2001; Hubbard, 2004, in press; Hubbard & Ruppel, 2002) suggested that decreased forward displacement of a launched target reflected an attribution that target motion was due to an impetus that was imparted from the moving object at the moment of contact and that dissipated with subsequent target motion. Such an impetus heuristic would allow approximately accurate predictions of target behavior (e.g., launched targets would move a short distance and then stop), would be simpler (one parameter) than a representation based on correct physical principles such as friction and air resistance (multiple parameters), and would be consistent with previous findings regarding naïve physics (e.g., McCloskey, 1983) and displacement (e.g., Kozhevnikov & Hegarty, 2001).

An impetus heuristic suggests that mental representation does not involve an accurate representation of objective physical principles governing an object's behavior. Consistent with this, implied mass (manipulated by varying target size) influences displacement only along the axis aligned with implied gravitational attraction, and this occurs regardless of the direction of target motion (for review, Hubbard, 2005). Hubbard (1997) suggested that this pattern reflected a subjective experience of mass (i.e., weight, the experience of mass along the axis of gravitational attraction) rather than an objective mass per se. It is not clear whether White's (2012) claim that "mass is not visually perceived, but motion properties that are determined by mass are" (p. 602) is consistent with this finding, as presumably one such "motion property" would suggest that greater (implied) mass should produce greater (representational) momentum. The suggestion that the displacement of a launched target reflects subjective experience is consistent with an impetus heuristic, as impetus is consistent with the observed consequences of launching (e.g., launched targets move a short distance and then stop). Such findings challenge White's (2012) claim that it is "important for dynamic variables such as masses, forces, and resistances to be accurately encoded in the stored representation" (p. 604) and suggest that representation encodes the subjective consequences of physical principles rather than encoding objective physical principles.

## Imagery

White (2012) claimed, "one mentally rotates an object by simulating the action of physically rotating it; the simulation then has similar properties to those of physical rotation, including the representation of forces" (p. 603). Given this, a larger physical object might offer more resistance and require more force to rotate, and so it might be predicted that the representation of a larger physical object would be mentally rotated more slowly; however, such a result has not been found (e.g., Suzuki & Nakata, 1988). White (2012) suggested that studies examining the effects of manual rotation on mental rotation (e.g., Sack et al., 2007) show that "mental rotation is a kind of action simulation that represents the dynamics of the simulated action" (p. 603). However, such studies focused on the effects of motor activity on imagery and not on the effects of imagery on perception. Also, studies in which imagery was used to simulate physical processes typically involved "offline" simulation not concurrent with perception (e.g., Schwartz & Black, 1999). If imagery is involved in concurrent simulation, and given that same-modality imagery interferes with concurrent perception (e.g., Craver-Lemley & Reeves, 1992; Segal & Fusella, 1970), then concurrent simulation might interfere with rather than facilitate perception (cf. White, 2012, Footnote 10). Even so, some researchers have suggested an active role for imagery in perception that is consistent with a concurrent simulation involving imagery (e.g., Kosslyn, 1994).

## Psychophysics

In extrapolating from human experience to a nonhuman stimulus that can exert more force than a human, White (2012) suggested, "the impression of force should not increase as much as the objective difference in forces would warrant" (p. 599). However, psychophysical experiments in which participants exerted force (e.g., lifted weights), and in which a variety of scaling methods and muscle groups were used, suggest that perceived force is related to actual muscle force by a power function with an exponent of 1.7 (for review, Jones, 1986). An exponent of 1.7 suggests that differences in perceived force increase faster than do differences in objective force. It is not clear why the visual perception of differences in force in a nonhuman stimulus (based on generalization from human haptic experience) would result in a pattern opposite from (rather than weaker than) haptic human experience, and so psychophysical data on the haptic perception of force do not seem

[5] The claim that dynamic information is incorporated in the functional architecture of the representation is supported by findings that representational momentum cannot be eliminated by top-down influences even if experimental participants are provided with (a) information regarding representational momentum and asked to guard against representational momentum in their responses (Courtney & Hubbard, 2008), (b) information regarding the location of the target (Hubbard, Kumar, & Carp, 2009), and (c) feedback regarding their responses (Ruppel, Fleming, & Hubbard, 2009).

consistent with White's (2012) claim. Also, the perceived force of an object pressing on the palm is related to actual force by a power function with an exponent of 1.1 (Stevens, 1975). Although an exponent of 1.1 suggests that differences in perceived force increase faster than do differences in actual force, the increase in the perceived force of an object on a person (exponent of 1.1) is slower than the increase in the perceived force of a person on an object (exponent of 1.7), and this might be consistent with the asymmetry in force perception in White (2007, 2009).

### Perception of Causality

White (2012) claimed, "if object A's motion was perceived as caused by another object, C, striking it, this would in no way prevent the launching effect from occurring when object A contacted object B" (p. 600). However, Michotte (1951/1991) reported that a configuration such as the one that White (2012) described led to a perception that the motion of object B was attributable to object C rather than to object A, and this was referred to as a *tool effect*. Such a configuration was not perceived as consecutive launching effects (i.e., not perceived as C launches A, then A launches B), and so the tool effect is inconsistent with White's (2012) claim. Also, there are examples in the literature on the perception of causality in which the causal object does not move. White and Milne (1999) reported the perception of causality if a moving object shattered upon contact with a stationary object. If a stationary object is perceived to cause the shattering of a moving object, then it could be predicted that the asymmetry in perceived force should be reversed (i.e., the stationary object perceived to exert more force on the moving object). Alternatively, White (2011) suggested that the "more active Object A is prior to contact, the more it may be perceived as the cause of its own demise" (p. 659), and this suggests the asymmetry in perceived force would not be reversed. However, comparisons of ratings of causality and ratings of force for a shattered object and for a stationary object have not been reported. Related examples in which the typical asymmetry of perceived force might also be reversed include the braking effect (Levelt, 1962) and the penetration effect (White & Milne, 2003), in which a moving object is slowed or stopped by a change in background or by the penetration of a barrier, respectively.

## Scope and Limitations

Issues in this section involve seemingly paradoxical attributions of intentionality and whether White's (2012) account is potentially falsifiable.

### Intentionality

Intentionality is both limited and widespread in White's (2012) account. White's (2012) claim, "seeing an organism act intentionally is, in effect, to see it producing motion by (voluntary) exertion" (p. 599) limits intentionality to voluntarily produced motion, thus focusing on acts of commission and ignoring acts of omission. Intentionality is also limited in that in the "perception of object motions and interactions, the focus is on features of the stored representations that relate most closely to forces . . . rather than on the antecedent mental states such as intentions" (p. 595).[6] Intentionality is widespread in that White (2012; following Michotte) suggested that the motion of object A toward object B in the launching effect "is objectively unlikely and is consistent with the hypothesis of intentional motion towards object B" (p. 600). This implies that motion toward an object is always initially perceived as intentional (and exhibiting voluntary exertion). However, a brief consideration suggests counterexamples. For example, when fragments of comet Shoemaker-Levy 9 hit Jupiter in 1994, were those fragments perceived as acting intentionally? White's (2012) account seems to also suggest that without a visible external source of motion, such comet fragments would be perceived as having an internal (and biological) source of motion. Although White's (2012) account suggests that we could use acquired knowledge to resist such a perception, such post hoc correction seems ad hoc and inefficient.

White (2012) suggested that the language of intentionality is limited to voluntary exertion and that the perception of voluntary exertion is limited to stimuli that move in a manner and tempo similar to humans; thus, he appeared to limit intentionality to stimuli that exhibit movement patterns similar to humans. However, intentional language can be, and often is, used in referring to nonbiological stimuli that do not move like humans. For example, Dennett (1987) discussed how the language of intentionality is used to describe the behavior of a stimulus if physical or design knowledge regarding that stimulus is lacking, and he referred to this as taking an "intentional stance" toward that object. Such an intentional stance involves projecting humanlike intentionality onto a nonhuman stimulus, and it is not necessary that the stimulus move like a human. Another example of the use of intentional language in the absence of movement similar to human movement is the Turing test (for review, Saygin, Cicekli, & Akman, 2000), and additional discussions of intentional language not solely dependent upon movement can be found in Malle, Moses, and Baldwin (2003) and Malle and Knobe (1997). White's (2012) attribution of intentionality only to objects that exhibit humanlike movement does not seem consistent with the broader uses of that term within the literature on intentionality.

### Falsifiability

Despite initially offering strong testable claims (e.g., "impressions of force will not occur in any kind of object motion that cannot be matched to any kind of human action," White, 2012, p. 599), White's (2012) account was eventually weakened so much as to be virtually unfalsifiable (e.g., "perceivers may make extrapolations beyond the range of human capacities," p. 599). Initially, effects on mechanoreceptors of human action formed the basis of knowledge regarding forces. If humans could not act in some way (e.g., if we could not move like a snake), then we would not have

[6] Wulf and Prinz (2001) reported motor learning is more effective if learners focus on the effects of their movements (i.e., the outcomes they intend) rather than on their movements (i.e., the forces they would produce). This pattern seems opposite from the focus on forces rather than on intentions that White (2012) proposed for perception. One possibility is that learning and perception each begin with what is more easily known by the person, with intention perhaps more easily known than are forces in learning, but with forces perhaps more easily known than are intentions in perception.

haptic information regarding forces relevant to that action, and so we would not visually perceive force in some other stimulus that acted (moved) in that way. As noted earlier, no part of a human body can rotate continuously in a single direction like a wheel, and given this, a perception of force in a rotating wheel should have falsified White's (2012) account that matching to human movement patterns was necessary for impressions of force. However, in this example, White (2012) abandoned the constraint that we cannot perceive forces in movements that are not matched to human patterns of movement, and he suggested that we can perceive force in a stimulus if we have previously interacted with a similar stimulus. Given that humans could potentially interact with stimuli that exhibited any type of motion, it appears there would not be any type of force we could not learn to perceive and, thus, no way to potentially falsify White's account.

## Conclusions

White (2012) provided an account for how impressions of force and exertion can occur in visual perception, and he takes a significant step in addressing an important problem in a neglected area of investigation. Some of White's (2012) claims appear consistent with previous findings and theories (e.g., feature matching in perception, filling in of missing information by previous knowledge, habituation). However, some claims do not appear consistent with previous findings and theories (e.g., lack of objectively correct encoding of dynamic variables, faster increases in perceived force than in actual force, use of intentional language). Other claims appear problematic (e.g., perception of force in objects that do not exhibit human patterns of movement [e.g., a vehicle in which wheels rotate continuously in the same direction]; the role of rules, cues, and heuristics; lack of falsifiability) or need clarification (e.g., how the relationship of force and resistance relates to asymmetries in perception, why perception of whether motion is internally or externally generated or is biologically or nonbiologically caused influences the perception of force, perceived force or resistance if the causal object is stationary and the effect object is in motion, whether simulation is necessary for the matching of kinematic features, role of imagery in concurrent simulation). White (2012) provided a useful framework to guide future research on the representation of force, but significant unresolved issues remain.

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Received September 26, 2011
Revision received March 19, 2012
Accepted March 22, 2012 ■