

The Locus of Stimuli Meaning in the Influence of Attention on Movement: Meaning-Dependent Response Activation Model

J.L. Vilchez

Universidad Internacional de La Rioja

Studies are reviewed regarding the influence of attention capture (in either an endogenous or an exogenous manner) on movement. Those studies used discrete-trial movements, such as grasping or reaching for an object, to account for that influence. This review and its conclusions are derived from a more ecological, realistic perspective, taking into account the possible application of future findings on real-life tasks. In general, previous models and theories have highlighted the spatial and temporal characteristics of the way stimuli present into the visual scene. This present work is not focused on analytical, physical features of stimuli, but on a holistic, mental meaning of stimuli's representation accounting for the distinct kinds of effect given on this cognitive-processes relationship. A new perspective is proposed, relying on the meaning a stimulus can have per se, or on the context wherein a stimulus is presented, to explain prior findings and to address future issues on this topic. This original account can be applied practically to scientific analysis, for example, of those points in roads with high likelihood of car crash — also known as “black spots” in road safety. It is assumed that current road designs do not take into account possible, non-obvious counterproductive effects given by the interaction of different meanings together and inserted in a determined context.

Keywords: movement, endogenous, exogenous

Spatial attention has been classically conceived within a setting of a supramodal control mechanism (see Posner and Dehaene, 1994, for a review) that improves the processing of sensory information coming from a determined part of environmental space. Nonetheless, Rizzolatti, Riggio, Dascola, and Umiltà (1987, for an introduction) challenged this classical view by proposing that the movement of attention is caused, in part, by the activation of common structures for the to-be-

performed action, thus introducing a completely new perspective. Current evidence for this assumption comes from a series of experiments where overlaps have been found for both underlying neuronal networks (Corbetta et al., 1998; Nobre, Sebestyen, and Miniussi, 2000) and similar differentiation of the areas that make up their structure in spatial coordinates (Rizzolatti, Riggio, and Sheliga, 1994). The so-called *premotor theory* (Rizzolatti et al., 1987) suggests that cognitive systems for attention and action are more closely linked than previously supposed; assuming that attention derives from preparation to move the eyes towards the cued location. Therefore, there is no need to postulate two distinct mechanisms for the control of attention and action. Evidence seems to support this assumption since, when the eyes cannot move towards a certain location, the attention cannot move either (Craighero, Carta, and Fadiga, 2001; Craighero, Nascimben, and Fadiga, 2004).

The concept of affordance affirms that the perception of any object elicits a response that can be carried out with that very object (see Tucker and Ellis, 1998, for a review). Tipper, Lortie, and Baylis (1992) proposed that this repertoire of available actions makes necessary the existence of an action-selection mechanism for deciding what action to perform in order to best achieve the subject's goals.

The perception both of target (defined as that stimulus which is related to a subject's goals) and distractor stimuli (those stimuli which are not related to the subject's goals) triggers the automatic initiation and parallel programming of suitable movements in response to each one and the subsequent inhibition of the interfering motor process elicited by the distractor. The consequence of this action-selection process is not only a longer reaction time by the subject but also a longer time for the entire movement compared with the same goal in the absence of distracters (Weir et al., 2003).

Coherent with the idea of the competition between target and distracters to emerge in behavior, various studies have dealt as well with the plausible spatial repercussions on movement (e.g., its trajectory). However, for some time these studies were inconsistent in their results, finding the trajectory of movement, in some cases, was veering towards the distractor allocation (Tipper, Howard, and Houghton, 1999) and, in other cases, away from it (Tipper, Howard, and Jackson, 1997). This literature (based on discrete-trial tasks with simple limb movements, such as reaching, aiming, or grasping) has suggested two main theoretical models that try to account for the pattern of results typically found.

Response Vector Model and Response Activation Model

The vector response model (Houghton and Tipper, 1999; Tipper et al., 1999) is based on evidence that, when responses are needed, different subpopulations of directionally-tuned cells are activated. In Georgeopoulos's (1990) studies,

the response programming in rhesus monkeys was determined by the vector sum of the preferred movements by a large population of neurons. Considering this, Tipper et al. (1999) assumed that in a complex environment with more than one stimulus, when both kinds of stimuli (target and distractor) are present at the same time, a population of neurons is activated — one for each stimulus.

This activation of neurons has a direction in the form of a vector. Tipper and colleagues proposed that the final movement carried out by subjects would be the result of the response competition and subsequent inhibition of one of these two populations of neurons. According to these authors, both populations are partially overlapped, thus both movement representations would interfere with each other. The vectors for both codifications would be affected and, therefore, the plausible unresolved response competition could produce a deviation towards the distractor at the moment of movement initiation as a consequence. The inhibitory mechanism would attempt to keep any one of the two responses from occurring (based on the subject's goal). If this inhibitory process becomes large enough, it not only could cancel the movement towards the distractor but even invert it, thus inhibiting not only the population of neurons for the movement-to-distractor codification, but also the amount of neurons shared with the movement-to-target one. The model posits that the deciding factor for the stronger or smaller activation of the inhibitory process relies on how salient the distractor is. Thereby, the more salient the distractor is, the stronger the activation of the inhibitory process would be, resulting in participants deviating from the position of the distractor for the ongoing to-target movement. On the other hand, the less salient the stimulus is, the smaller the activation of the inhibitory process would be, therefore allowing the activation of distractor programming response to partially remain, resulting in a slight deviation towards the allocation of the distractor.

The response vector model was refuted by the response activation model proposed by Welsh and Elliot (2004). This model is based on a partial overlap of the movement codifications towards the target and distractor stimuli (as the previous model is), but it postulates that the inhibitory process of the response codified towards the distractor is always the same, and that process requires some time to execute and complete its action. Therefore, the differential effects on movement found in the previous literature (attractive or repulsive) can be explained as caused by different stages of the inhibitory process wherein the influence of a distractor in the movement towards the target is ascertained. To test this hypothesis, Welsh and Elliot (2004) used several SOAs (target/distractor stimulus-onset asynchronies) to check what happens when an inhibitory process is given a larger or a smaller amount of time. Welsh and Elliot's results show that when the participant is given a certain amount of time (750 ms) between the appearance of the distractor and the appearance of the target, the final movement veers away partially (in spatial terms, between other parameters)

from the position of the distractor. That is to say, when the inhibitory process completes its action, the system cannot count on the overlapping part of the neurons between both movement codifications to execute the movement towards the target, since that shared population of neurons is inhibited at the time of conducting the ultimate movement. When the participant's inhibitory process is not given sufficient time to inhibit the response towards the distractor (250 ms), the final movement approaches partially (also in spatial terms) the allocation of the distractor. In other words, in this case, when the inhibitory process has not completed its action, there is some activity remaining in the system, belonging to the codification of the movement towards the distractor.

Types of Attentional Cue and Effects on Movement

Before Welsh and Elliott (2004) began to analyze the time course of the inhibition process, Lee (1999) reported on the kinds of stimuli that could influence movement trajectory. There are at least two distinct modes of attentional control, according to Jonides (1981). The exogenous mode, amongst other characteristics, triggers a priming effect, captures attention automatically, and facilitates the processing of stimuli presented in the same area shortly afterward. In contrast, the endogenous control develops more slowly and in a voluntary manner.

According to Lee (1999), the majority of studies dealing with this topic have had a limited concept of movement, given that they focus only on the influence attention has on reaction times, using solely non-continuous key-pressing tasks to test the plausible effects. Lee's work aimed to show that attention could also influence other aspects of movement, such as the initial direction of a movement or its trajectory. Only a few studies before the work of Lee had examined this issue and, in those, cued locations never became targets of the movement. Lee, using both endogenous and exogenous cues and checking if there were significant differences in the initial direction of the movement, tested the effect of giving meaning to the cue. Hence, the main hypothesis was to verify whether a priming effect could be attained depending on the meaning given to the cue; in other words, presenting a valid cue in the space which could be later occupied by a target.

In order to show both kinds of influence, a tracking reflective marker with a 3D electro-optic sensor monitored participants' hand movements (Lee, 1999). Participants sat facing a computer monitor on which concentric circles were constantly displayed in the centre of the screen. Four small grey circles were presented around the circumference of the large circle, remaining equidistant from each other. The central red circle was illuminated at the beginning of every trial. When it was turned off, another of the four circles situated around the circumference of the large grey circle was illuminated in red. Participants were instructed to relocate a feedback cursor as quickly as possible on the one peripheral circle illuminated in red.

For the first experiment of the series, Lee (1999) examined the effects of peripheral/exogenous cues (a light cueing one of the four small circles) on the initial direction and latency of hand movements. On each trial, movement initiation was divided into intervals with limits of 0, 100, 200, and 300 ms and the spatial relationship between target and cue had four possible values: 0, $\pm 90^\circ$, and 180° (in an anti-clockwise direction). The results showed that when the target was preceded by an invalid cue, the latency between the appearance of the target and the initiation of the response increased compared to the control condition with no cues. For latencies of less than 200 ms, hand movements veered towards the cue, while for those greater than 300 ms, the majority veered towards the target. When the latency was between 200 and 300 ms, the direction of the movement was strongly influenced by the relationship between the positions of cue and target. Likewise, when the spatial relationship between them was 180° , the movement could be initiated towards either the target or the cue, the difference being average. However, when the spatial relationship was 90° , the initiation of the movement gradually changed from a movement towards the cue to a movement towards the target, in accordance with the rise in latency of initiation.

The subsequent experiments attempted to determine whether the central/endogenous cues (a line segment pointing to one of the four plausible peripheral circles this time) could have the same effect on movement direction as the exogenous one did, and how the two types of cueing interacted. The results of these experiments showed that endogenous cues provoke an effect on movement with the same characteristic that the exogenous one does and exogenous and endogenous cues do not interact with one other (which means that their effects are essentially the same). Indeed, Lee (1999) found that with both types of cue, only those movements wherein distractors had been presented in a $\pm 90^\circ$ position from the target and with a determined movement initiation (between 200 and 300 ms after the appearance of the target) began with an initial veering to some point between target and cue positions, and were gradually corrected thereafter.

Although Lee (1999) did not properly quantify the time course of this inhibition (using only ad hoc time intervals), the main contribution of this series of experiments was to demonstrate that both kinds of cue (exogenous and endogenous) can influence movement execution. A secondary importance was the demonstration of the relevance of the possible meaning that a cue has in the determination of its effect on movement.

Relevance of Meaning and Context for Movement

The results above show the link between attention and action on discrete-trial-task movements unlike eye-tracking movements (classically used for supporting the premotor theory). However, at a certain point it was necessary to

test to what extent and in which direction the shown effects could be relevant for more real tasks, like driving. With that aim in mind, our own research (Vilchez and Tornay, 2012) used a tracking task normally conceived as a simplified version of a real driving context that has been often used in ergonomic research (see Wickens and Hollands, 2000, for a review).

Since previous studies were based on discrete trials, they were limited to a determined set of possible positions for target and distractor. The tracking task, even when it is a simplified driving task, allows presenting multiple distractors in multiple positions and an animation that seems continuous to the participant, which makes the task more realistic. This methodology registers a individual's movement frame by frame (which produces a large amount of information), allowing a deeper analysis of the behavior (such as in Lee's 1999 studies) and, especially, the possibility of measuring the continuous, ongoing movement as well (which was an original point in this research line).

A series of experiments (Vilchez and Tornay, 2012) were conducted to determine whether the simple presentation of an exogenous cue (singleton) could exert an influence on movement execution. A simulated black road with a continuous, yellow middle and bordering lines appeared on a computer screen with a green background. The participants controlled a blue circle considerably smaller than the width of the road, and a red singleton appeared randomly on almost any part of the screen (at no time were two distractors presented simultaneously).

A veering away effect was found from the allocation of the distractor (exogenous cue) on the trajectory of the blue circle controlled by participants for following the middle line of the road. Specifically, the mean trajectory deviation when there was no distractor increased gradually in the opposite direction to the allocation where the distractor was presented. That is to say, when distractors were presented on the left side of the blue circle, the mean of deviations was displaced to the right (taking more positive values), compared to the mean of deviations when the distractor was not present. Likewise, when distractors were presented on the right of the blue circle position, the mean of deviations rose towards the left (taking more negative values). Given that a similar pattern of results was found in all experiments using distinct peripheral devices for controlling the movement, it is possible to affirm that this effect does not depend on either the type of movement control device or the particular muscles involved in operating it. The fact that the movement is always away from the distractor is at odds with Welsh and Elliott's (2004) response activation model — which was so far the only unfalsified model in the literature — after they showed that the response vector model could not explain even the data in the discrete-trial task used in Welsh and Elliott's studies. With these new findings, there does not seem to be a second phase (as the response activation model would pound) in which the movement is directed towards the distractor when

the action of the inhibitory process begins to emerge in behavior. The possible meaning of “obstacle” or “danger” in this context (given the overlap of the distractor on the road, the abrupt invasion of the visual scene, and the appearance in unpredictable positions), seems to be behind this completely veering-away movement. This gives a more holistic rather than purely analytical perspective to the topic (see Ganel and Goodale, 2003, for a review of both concepts).

This action meaning-dependency is not new in the literature. Biersner and Melzack (1966), using two kinds of frogs (*rana pipiens* and *rana castesbeiana*), showed that those animals approached or avoided objects moving towards them depending on object-size. There was a critical size for which smaller objects were approached and larger ones were avoided. The rationale underneath these findings seems to rely on the meaning of something-I-can-eat or something-that-can-eat-me, since for the larger frogs (*rana pipiens*) the critical object-size for approaching or avoiding was significantly larger as well (increasing the rage of something-that-I-can-eat). The meaning that individuals give to stimuli not only determines the action to be performed but the manner in which it is conducted. In a series of experiments, as an example, Buckingham, Cant, and Goodale (2009), using illusory visual cues, showed how the grip and load forces for lifting objects can be influenced based on participants’ expectations.

Meaning-Dependent Activation Model

Taking into account the data from our own studies (along with the results from Lee’s 1999 studies), a revision of the response activation model by Welsh and Elliott (2004) can be undertaken. Under these new findings of a continuous effect with neither different phases of the inhibition process nor a turning point in which the effect passes from a repulsive effect to an attractive one or vice versa, this model remains unsubstantiated. The hypothesis, derived from our own work (Vilchez and Tornay, 2012), revolves around the fact that the meaning given to the distractors causes the differential effects on movement. According to this new explanatory perspective, where the main referent is the distractor’s meaning, Welsh and Elliott’s (2004) data could be differently explained. Presenting the distractor/non-target stimuli in different time intervals causes their meaning to be perceived in a qualitatively different manner. In other words, in the 750 ms condition, the subject can distinguish that the distractor is not really the target of the task; therefore, the final codification conducted on the target is repulsive. When the movement is executed towards the target, the resulting movement is a mixture of the non-target repulsive codification (partially inhibited, but with remaining activity) and the target attractive codification. Since the movements were conducted in the same spatial line, the final movement veers away partially from the non-target because of the remaining activity from the codification meaning something-to-move-away-

from (repulsion movement, without requiring the codifications of such movements to be neutrally overlapped). In the 250 ms condition, the participant does not distinguish appropriately the meaning of the non-target stimulus and, as it could be a target, it codifies its meaning as something-to-move-close-to (attractive movement). Therefore, when the final movement is conducted towards the target, the resulting movement contains the codification attracted towards the non-target (which is conceived as a possible target).

In Lee's (1999) studies, there is evidence to support this conception. For latencies of initiation under 200 ms, there is no time for participants to distinguish the actual meaning of the cue/non-target (which could be a target), hence, the initial direction is programmed under the codification of a possible target (something-to-move-close-to) and, as a result, the hand movements veered toward the cue (attractive movement). For latencies of initiation over 300 ms, there is enough time to properly distinguish the real meaning of the cue/non-target, therefore, the codification of the initial direction is something-to-move-away-from and, as a result, the hand movements are initiated toward the target (repulsive movement to the cue allocation). Finally, for latencies between 200 and 300 ms, both codifications are active (attractive to both kinds of stimuli, target, and cue). The initial direction, as a result of the response competition, is a mixture between both directions towards both stimuli, which depends, in turn, on the spatial relationship between target/cue (just for $\pm 90^\circ$ positions, given that, for 180° and 0° distractor-target positions, movements are carried out in the same line).

The relevance of the meaning that a stimulus can have is evidenced in everyday situations. For instance, when we pick up a very hot object, we do not only inhibit the response we were codifying. If we did so, we would remain close to the object and we would simply stop coming closer to it. What we also do is to codify another repulsive movement towards the object that is hurting us because its new meaning is pain.

Welsh (2011) has recently reviewed his own model but, in spite of citing Lee's (1999) study, Welsh failed to realize the importance of meaning in the codification of movement. Admittedly, Lee did not point this out *per se*, but Welsh should have understood the essence of distractor/non-target stimuli for explaining their effects on movement.

The justification for the system to engage attention on some stimuli and not on others (Folk, Remington, and Johnson, 1992) is the match between target and non-target characteristics. This argumentation was already pointed out in the theory of event coding (see Hommel, Müssele, Aschersleben, and Prinz, 2001, for an introduction), in which a partial matching between the features of the representation of both the perceiving stimulus and the voluntary action for that stimulus would provoke an interaction between action-related processes (in this case for both target and non-target). Even though this totally new postulate

for the response activation model (Welsh, 2011) would partially explain the effects found on movement using stimuli (targets and non-targets) with similar characteristics, there remains the question of “why an irrelevant-for-a-task and non-similar singleton can cause a repulsive effect on movement in a tracking task?” (Vilchez and Tornay, 2012). In our prior studies, the used singleton was a red small circle that did not share any characteristic with a black simulated road (with a continuous middle and bordering yellow lines). It is evident that this kind of stimulus, under response activation model assumptions (Welsh, 2011), could not capture attention but, even though so, it did trigger a clear, complete repulsion effect (Vilchez and Tornay, 2012).

The meaning that a stimulus can have in an ascertained context as the base of explanation for the effects of attention on movement (found in the literature) would be conceptually closer to the ideomotor phenomenon (Carpenter, 1852). In our experiments (Vilchez and Tornay, 2012), the appearance of a non-target/distractor stimulus in unpredictable positions overlapped on the road and with an abrupt invasion of the visual scene could rationally trigger the meaning of danger. This highlights the influence of past experience in current behavior (e.g., Arrington, Weaver, and Pauker, 2010; Buckingham and Goodale, 2010; Lien and Ruthruff, 2008). The meaning could successively evoke the automatic, vivid representation of any dangerous circumstance. This can be seen in Rothi, Raymer, and Heilman (1997): the new stimulus perceived derives from the input praxicon (a long-term mnemonic structure for storing visual attributes). That idea of danger would provoke, in turn, the action-related process of escape (or something-to-move-away-from), recruiting it from the output praxicon (another structure for performance-related sensational or perceptual codes in the form of motor programs). This visuo-kinaesthetic relationship would be conceptually also close to the concept of affordance (Tucker and Ellis, 1998) in the sense of triggering the suitable response for the ongoing experience-related representation.

Taking into account all theories and assumptions reviewed above, a new and original model is proposed. The meaning-dependent response activation model posits the following: there are different codifications for different stimuli, without the premise (used by previous models) of the necessary existence of an overlap between the codifications corresponding to the target and distractor stimuli; dependence on the kind of codification (such as attractive or repulsive) according to the meaning the stimulus has or the individual provides to it — not the stimulus saliency per se or its shared characteristic with other stimuli in the visual scene; and the existence of an efficient but not completely effective inhibitory mechanism to leave out the competitive, unsuitable responses triggered by distractors — since the presence of the distractors causes a significant and involuntary effect on the movement until it is totally inhibited, as described in our own and all reviewed studies.

It can be argued that the meaning-dependent response activation model provides a more accurate way of describing not only the effect of attention on movement for trial-discrete tasks but for closer-to-daily-life tasks and is, therefore, a more useful tool in analyzing cognitive ergonomic situations. As an example of this last point, it currently remains unclear what kind of meaning a traffic sign (or other kind of roadside element) can have for an individual in specific contexts and, hence, what counterproductive effect it could have on movement in certain situations. Future works will be driven in that direction.

References

- Arrington, C.M., Weaver, S.M., and Pauker, R.L. (2010). Stimulus-based priming of task choice during voluntary task switching. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 36, 1060–1067.
- Biersner, R., and Melzack, R. (1966). Approach–avoidance responses to visual stimuli in frogs. *Experimental Neurology*, 15, 418–424.
- Buckingham, G., Cant, J.S., and Goodale, M.A. (2009). Living in a material world: How visual cues to material properties affect the way that we lift objects and perceive their weight. *Journal of Neurophysiology*, 102, 3111–3118.
- Buckingham, G., and Goodale, M.A. (2010). The influence of competing perceptual and motor priors in the context of the size–weight illusion. *Experimental Brain Research*, 205, 283–288.
- Carpenter, W.B. (1852). On the influence of suggestion in modifying and directing muscular movement, independently of volition. *Proceedings of the Royal Institution of Great Britain*, 1, 147–153.
- Corbetta, M., Akbudak, E., Conturo, T.E., Drury, H.A., Linenweber, M., Ollinger, J.M., Petersen, S.E., Raichle, M.E., Van Essen, D.C., Snyder, A.Z., and Shulman, G.L. (1998). A common network of functional areas for attention and eye movements. *Neuron*, 21, 761–773.
- Craighero, L., Carta, A. and Fadiga, L. (2001). Peripheral oculomotor palsy affects orienting of visuospatial attention. *NeuroReport*, 12(15), 3283–3286.
- Craighero, L., Nascimben, M., and Fadiga, L. (2004). Eye position affects orienting of visuospatial attention. *Current Biology*, 14(4), 331–333.
- Folk, C.L., Remington, R.W., and Johnston, J.C. (1992). Involuntary covert orienting is contingent on attentional control settings. *Journal of Experimental Psychology: Human Perception and Performance*, 18, 1030–1044.
- Ganel, T., and Goodale, M.A. (2003). Visual control of action but not perception requires analytical processing of object shape. *Nature*, 426, 664–667.
- Georgeopoulos, A.P. (1990). Neurophysiology of reaching. In M. Jeannerod (Ed.), *Attention and performance* (Volume XIII, pp. 227–263). Hillsdale, New Jersey: Lawrence Erlbaum.
- Hommel, B., Müsseler, J., Aschersleben, G., and Prinz, W. (2001). The theory of event coding (TEC): A framework for perception and action planning. *Behavioral and Brain Sciences*, 24, 849–937.
- Houghton, G., and Tipper, S.P. (1999). Attention and the control of action: An investigation of the effects of selection on population coding of hand and eye movement. In D. Heinke, G.W. Humphreys, and A. Olsen (Eds.), *Connectionist models in cognitive neuroscience [Proceedings of the 5th Neural Computational and Psychological Workshop]*. New York: Springer Verlag.
- Jonides, J. (1981). Voluntary versus automatic control over the mind's eye's movement. In J.B. Long and A.D. Baddeley (Eds.), *Attention and performance* (Volume IX, pp. 187–203). Hillsdale, New Jersey: Erlbaum.
- Lee, D. (1999). Effects of exogenous and endogenous attention on visually guided hand movements. *Cognitive Brain Research*, 8(2), 143–156.
- Lien, M.C., and Ruthruff, E. (2008). Inhibition of task set: Converging evidence from task choice in the voluntary task-switching paradigm. *Psychonomic Bulletin and Review*, 15, 1111–1116.
- Nobre, A.C., Sebestyen, G.N., and Miniussi, C. (2000). The dynamics of shifting visuospatial attention revealed by event-related potentials. *Neuropsychologia*, 38, 964–974.

- Posner, M.I., and Dehaene, S. (1994). Attentional networks. *Trends in Neuroscience*, 17, 75–79.
- Rizzolatti, G., Riggio, L., Dascola, I., and Umiltà, C. (1987). Reorienting attention across the horizontal and vertical meridians: Evidence in favor of a premotor theory of attention. *Neuropsychologia*, 25, 31–40.
- Rizzolatti, G., Riggio, L., and Sheliga, B. (1994). Space and selective attention. In C. Umiltà and M. Moscovitch (Eds.), *Attention and performance* (Volume XV, pp. 231–265). Cambridge, Massachusetts: MIT Press.
- Rothi, L.G., Raymer, A.M., and Heilman, K.M. (1997). Limb praxis assessment. In L.G. Rothi and K.M. Heilman (Eds.), *Apraxia: The neuropsychology of action* (pp. 61–74). Hove, United Kingdom: Psychology Press.
- Tipper, S.P., Howard, L.A., and Houghton, G. (1999). Behavioral consequences of selection from neural population codes. In S. Monsell and J. Driver (Eds.), *Attention and performance* (Volume XVIII, pp. 223–245). Cambridge, Massachusetts: MIT Press.
- Tipper, S.P., Howard, L.A., and Jackson, S.R. (1997). Selective reaching to grasp: Evidence for distractor interference effects. *Visual Cognition*, 4, 1–38.
- Tipper, S.P., Lortie, C., and Baylis, G.C. (1992). Selective reaching: Evidence for action-centred attention. *Journal of Experimental Psychology: Human Perception and Performance*, 18(4), 891–905.
- Tucker, M., and Ellis, R. (1998). On the relations between seen objects and components of potential actions. *Journal of Experimental Psychology: Human Perception and Performance*, 24(3), 830–846.
- Vilchez, J.L., and Tornay, F.J. (2012). Irrelevant stimuli produce a path deviation in a driving-simulation task. *Cognitive Systems Research*, 17–18, 81–89.
- Weir, P.L., Weeks, D.J., Welsh, T.N., Elliott, D., Chua, R., Roy, E.A., and Lyons, J. (2003). Influence of terminal action requirements on action-centered distractor effects. *Experimental Brain Research*, 149, 207–213.
- Welsh, T.N. (2011). The relationship between attentional capture and deviations in movement trajectories in selective reaching tasks. *Acta Psychologica*, 137, 300–308.
- Welsh, T.N., and Elliott, D. (2004). Movement trajectories in the presence of a distracting stimulus: Evidence for a response activation model of selective reaching. *The Quarterly Journal of Experimental Psychology*, 57A(6), 1031–1057.
- Wickens, C.D., and Hollands, J.G. (2000). *Engineering psychology and human performance*. Upper Saddle River, New Jersey: Prentice Hall.