

Running head: EMBODYING ROUTE DESCRIPTIONS

Moving through Imagined Space: Mentally Simulating
Locomotion during Spatial Description Reading

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Abstract

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Readers mentally simulate the perceptual and motoric elements related through text. Sound is one perceptual characteristic of these embodied simulations that has received little attention.

Two experiments tested whether movement sounds (walking vs. running) or metronome pulses (fast vs. slow) would modulate reading speed and memory for two different types of spatial descriptions, route and survey. Route descriptions describe environments from a first-person, ground-level perspective whereas survey descriptions use an aerial overview perspective. Experiment 1 demonstrated that route description readers altered their reading speed in correspondence with both movement and metronome sounds, progressing through descriptions faster when hearing fast paced versus slow paced sounds. When reading survey descriptions, however, readers only modulated their reading speed while listening to metronome pulses. Those who showed the greatest reading time effects with the route description and footstep sounds also showed difficulty solving inferences from the survey perspective. Experiment 2 demonstrated that movement sounds influenced perceptions of distance traveled such that estimates of environmental scale increased after listening to running versus walking sounds. Taken together these results demonstrate that route description readers mentally simulate a journey through a described world, and these simulations and the resulting spatial memories can be guided by auditory information.

Moving through Imagined Space: Mentally Simulating Locomotion during Spatial Description Reading

During discourse comprehension, readers are guided along with described characters on journeys through environments and the events that take place along the way, discovering information about such things as time, space, intentionality, and causation (Zwaan & Radvansky, 1998). Some work suggests that these types of mental representations formed during reading are grounded in the perceptual and motoric systems that also govern direct perception and action (Barsalou, 2008). Readers may actively generate a comprehensive mental simulation that represents described or expected motor movements and perceptions, and these simulations are important components of successful comprehension (for recent reviews see, Fischer & Zwaan, 2008; Glenberg, 2007; Zwaan & Rapp, 2006).

The present work specifically investigates readers' mental simulations of imagined journeys through described environments as conveyed by spatial descriptions. Spatial descriptions are a common mechanism for communicating information about environments and typically adopt one or more perspectives (Golledge, 1992; Siegel & White, 1975; Taylor & Tversky, 1992a, 1992b). Survey descriptions take an aerial overview perspective and describe an environment's overall layout, and route descriptions take a ground-level perspective suitable for describing paths and turns towards a destination. Recent work with spatial descriptions has raised the possibility that route descriptions may promote active mental simulation of the perceptual and motoric elements comprising the text, whereas survey descriptions may not (Brunyé & Taylor, 2008a; Pazzaglia, De Beni, & Meneghetti, 2007). Specifically, route description readers may imagine themselves moving through the

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4 environment, seeing described scenes, and overall maintaining a vivid sense of ‘being there.’
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6 This view is in line with much recent work suggesting that readers covertly simulate the
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8 perceptual and motoric elements comprising many described situations (Barsalou, 2008;
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10 Brunyé, Ditman, Mahoney, Augustyn, & Taylor, 2009; Fincher-Kiefer, 2001; Glenberg,
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12 1997; Glenberg & Kaschak, 2002, 2003; Stanfield & Zwaan, 2002; Wilson, 2002; Zwaan,
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14 2004; Zwaan & Taylor, 2006). Survey descriptions, in contrast may promote the
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16 development of external-perspective ‘mental maps’ that depict an environment from a bird’s-
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18 eye perspective; these mental maps likely do not code specifically for the perceptual and
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20 motor information inherent to imagining movement through an environment at a ground
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22 level.
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29 One relatively understudied issue is the extent to which multimodal information can
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31 be integrated into developing mental models of described space. Most work investigating the
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33 mental simulation of described events has been restricted to coupling visual and motor
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35 systems. However, other perceptual modalities may be incorporated into the mental
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37 simulations. For example, in mentally simulating a route through an environment, readers
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39 might incorporate auditory simulations such as footsteps, traffic, chirping birds, and voices,
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41 and these sounds might shape both the mental experience of a route and readers’ resulting
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43 memories of environments.
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49 To test the possibility that readers differentially embody route and survey spatial
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51 descriptions, and that sound might affect comprehension and memory for spatial
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53 descriptions, we conducted two experiments. The first asked whether sound cues may guide
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55 self-paced reading. These sounds were comprised of footsteps (walking versus running) or
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57 metronome pulses (slow versus fast). We are interested in whether readers would be more
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4 likely to mentally simulate the perceptual and motor characteristics of route relative to survey
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6 descriptions, and thus use footstep cues to guide reading speed. The second experiment asks
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8 whether these same sounds during the learning of spatial descriptions might affect readers'
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10 memory for environments.
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13 *Spatial Descriptions*

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16 The present work specifically investigates two types of spatial descriptions: route and
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18 survey. Route descriptions are a verbal analogue to navigation, and adopt an egocentric
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20 perspective, meaning that a reader is guided on an imaginary first-person tour through the
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22 environment and all spatial information is referenced to their dynamic position. As such,
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24 route descriptions typically contain explicit reference to the reader as the subject moving
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26 through the environment, such as by directly addressing the reader by using the pronoun
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28 'you' (i.e., Brunyé, Ditman, Mahoney, Augustyn, & Taylor, 2009; Ditman, Brunyé,
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30 Mahoney, & Taylor, in press). Survey descriptions are more like verbal analogues to maps,
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32 as they communicate spatial information from an aerial, allocentric perspective, and this
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34 information is bound to an external reference, most commonly canonical coordinates (north,
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36 south, east, west). As such, survey descriptions typically contain no reference to the reader,
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38 any implied character, or movement through an environment.
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46 Whereas route and survey descriptions have various linguistic and perspective
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48 differences, they have been found similarly effective at conveying spatial information to
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50 readers (Taylor & Tversky, 1992). In fact, recent work demonstrates that with sufficient
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52 experience with either description type readers develop what have been termed *spatial*
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54 *mental models* (Brunyé, Rapp, & Taylor, 2008; Brunyé & Taylor, 2008a,b). These models
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56 are abstracted memory representations that appear flexibly unbound to the perspectives
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4 characterizing the descriptions and also support inferences about the described environments
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6 (but see Shelton & McNamara, 2004). Critically, with either description type, readers can
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8 develop memory representations that can be used to solve complex problems both within and
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10 outside of the learned perspective.
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14 There is emerging consensus that while route descriptions are quite effective at
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16 conveying spatial information, this is not without cost. First, route descriptions tend to elicit
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18 slower reading times and require extended experience in order for readers to develop
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20 functionally similar representations to those resulting from even limited experience with
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22 survey descriptions (Brunyé, Rapp, & Taylor, 2008; Brunyé & Taylor, 2008b; Lee &
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24 Tversky, 2005; Noordzij & Postma, 2005; Noordzij, Zuidhoek, & Postma, 2006). Second,
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26 route descriptions tend to demand multiple working memory resources towards their
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28 effective processing (Brunyé & Taylor, 2008b; De Beni, Pazzaglia, Gyselinck, &
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30 Meneghetti, 2005; Deyzac, Logie, & Denis, 2006; Pazzaglia et al., 2007). There are several
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32 possible characteristics of route descriptions that might contribute to these processing
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34 differences. Route descriptions, unlike their survey counterparts, present spatial information
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36 embedded within a framework that necessitates continual updating of turns, paths, and
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38 distances during reading. This updating process recruits a high degree of central executive
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40 (cf. Baddeley, 1992) resources, in line with work suggesting the involvement of this working
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42 memory system in temporal sequencing (Brunyé, Taylor, Rapp, & Spiro, 2006; Brunyé &
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44 Taylor, 2008a; Miyake, Friedman, Emerson, Witzki, & Howerter, 2000; Miyake & Shah,
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46 1999). Route descriptions also require readers to infer landmark locations, whereas this
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48 information is directly provided by survey descriptions (Brunyé & Taylor, 2008a; Tversky,
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50 1993). Most relevant to the present work, route description readers may actively generate
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4 complex mental imagery of environments, incorporating any available perceptual and
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7 motoric information that can be derived from the description itself or external to the
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9 description. Evidence for this possibility comes from studies showing increased visuospatial
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11 working memory demands during route relative to survey or non-spatial procedural
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13 description reading (Brunyé & Taylor, 2008a; De Beni et al., 2005; Fincher-Kiefer, 2001;
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15 Pazzaglia et al., 2007), and anecdotal reports during participant debriefings (e.g., “I imagined
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17 seeing a dog as I walked by the park”).
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20 21 *Embodied Language Comprehension*

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23 Further evidence that readers mentally experience the objects, events, characters, and
24
25 movements described in a text comes from research on event simulation and mental imagery.
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27 Indeed a variety of research suggests that readers actively form mental imagery of objects
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29 that match the conceptual meanings developed during language comprehension (e.g.,
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31 Stanfield & Zwaan, 2002; Yaxley & Zwaan, 2007; Zwaan, Stanfield, & Yaxley, 2002). For
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33 instance, reading about an object primes the availability of actions typically performed upon
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35 the object and, conversely, reading about actions primes the perceptual availability of
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37 associated objects (Borghi, Glenberg, & Kaschak, 2004), and even inhibits the performance
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39 of incompatible actions (Glenberg & Kaschak, 2002; Richardson, Spivey, McRae, &
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41 Barsalou, 2003). Further evidence comes from work demonstrating that readers embody the
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43 protagonists’ perspectives and mentally simulate their movements, sights, and interactions
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45 (see also, the *spatial distance effect*; Bower & Morrow, 1990; Bower & Rinck, 2001; Horton
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47 & Rapp, 2003; Rinck & Bower, 2000; Morrow, 1994; Morrow, Bower, & Greenspan, 1989;
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49 Morrow, Greenspan, & Bower, 1987; Rapp, Klug, & Taylor, 2006; Rapp & Taylor, 2004;
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51 Zwaan & Rapp, 2006). It is becoming increasingly apparent that there are strong ties between
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4 objects and actions, and the perceptual and conceptual representations of these are used to
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7 guide language comprehension (for reviews see Fischer & Zwaan, 2008; Glenberg, 2007).
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9 Converging evidence for the activation of perceptual and motor systems during
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11 reading comes from work demonstrating similar brain activity during actual perception and
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13 motor preparation as that found when readers mentally simulate the sensorimotor information
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15 conveyed by texts. Tettamanti and colleagues (2005) found that listening to first-person
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17 action sentences activates the same motor circuits that subserve action execution and
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19 observation. Kemmerer and colleagues (2008) demonstrated that brain activity during the
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21 reading of single verbs associated with five semantic concepts (action, motion, contact,
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23 change of state, and tool use) is very similar to that found with execution, observation, and
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25 imagination of these same types of actions (see also Bergen & Chang, 2005; Barsalou, 2005,
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27 2008; Kemmerer, in press).
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33 The present work investigates the possibility that, in addition to monitoring the visual
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35 and motoric elements described in a text, readers may also simulate described or implied
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37 sounds. Research in this regard is very limited. Tajadura-Jimenez, Valjamae, and Vastfjall
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39 (2008) recently found that varying the speed of heartbeat sounds during a picture rating task
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41 increased physiological arousal, image arousal ratings, and subsequent recall, suggesting that
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43 participants embodied heartbeat sounds to the extent that they altered their physiology and
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45 memory. Kurby, Magliano, and Rapp (2009) recently demonstrated that readers mentally
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47 simulate familiar characters' voices (i.e., *Auditory Imagery Experiences*), leading to faster
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49 probe verification when verbal probes are presented in a voice that is congruent versus
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51 incongruent with a familiar character.
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Experiment 1

The primary goal of our first experiment is to assess the relative degree of mental simulation involved during the reading of route and survey descriptions. Given the recent evidence for processing differences between route and survey descriptions, and other evidence for embodied language comprehension, it follows that route descriptions will evoke a higher degree of sensorimotor mental simulation during reading. We investigate this issue by using walking and running footstep sounds that have clear ties to both perception and motor movement, and ask whether transitions in footstep pace will lead to corresponding transitions in reading speed with spatial descriptions presented in route or survey perspectives. We expect that reading speed should be relatively slow when participants read while listening to walking sounds as compared to when they read while listening to running sounds; further, this effect will be specific to route and not survey description reading. This hypothesis is based on the fact that route description reading has been associated with the activation of both perceptual and procedural motor imagery during reading, whereas survey description reading has only been associated with perceptual imagery (i.e., Brunyé et al., 2008a; Gyselinck et al., 2007; Kuipers, 1983; Lovelace, Hegarty, & Montello, 1999; Noordzij, Zuidhoek, & Postma, 2006; Perrig & Kintsch, 1985; Taylor & Tversky, 1992); it is only the former that should be strongly associated with, and thus driven by, the motoric walking cues. Further, given that footsteps potentially evoke a ground-level perspective that is conceptually incongruent with a developing mental model during survey descriptions, they are not expected to modulate reading times with that description perspective (in fact, one possibility is that they may interfere with rather than facilitate reading times). As a control, we use metronome pulses matched to the footsteps for pace and amplitude (in Hz), but that

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4 primary dependent measure was reading speed measured as average amount of time
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6 participants took (in msec per syllable) to advance from sentence to sentence during reading.
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8 Our secondary dependent measures were accuracy and response times derived from a
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10 statement verification task designed to assess participants' memory for the environments as a
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12 function of description perspective and sound type.
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15 16 *Materials*

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19 *Spatial Descriptions.* Four pairs of texts were chosen from Taylor and Tversky
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21 (1992), the convention center, zoo, resort and town, each describing an environment from
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23 two perspectives: survey and route (see Appendix A). The survey descriptions were
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25 organized such that readers would receive relatively global then local information, and used
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27 canonical terms (*north, south, east, west*). The route descriptions guided readers on a linear
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29 tour through the environment, making the fewest possible turns while noting every landmark
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31 along a single continuous path. The eight descriptions provide all necessary and relevant
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33 spatial information needed to develop comprehensive memories of the environments, are
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35 equally coherent according to pilot judgments (Taylor & Tversky, 1992), and have been
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37 extensively used (e.g., Brunyé & Taylor, 2008a, 2008b; Shelton & McNamara, 2004).
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43 We modified the first sentence of each description to include information about the
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45 type of ground surface comprising the environment; in all cases we used gravel (e.g., "The
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47 convention center was erected on a vacant gravel parking lot."), which was identified in a
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49 pilot study (N = 6) as having the highest auditory distinctiveness ($M = 4.0$, $SD = 1.2$; on a
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51 Likert scale from 1-not at all distinctive, to 5-very distinctive) relative to paved ($M = 2.0$, $SD =$
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53 $=.89$), dirt ($M = 2.5$, $SD = 1.1$), grassy ($M = 2.2$, $SD = 1.2$), or cobblestone ($M = 2.3$, $SD =$
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55 1.0) surfaces. This difference was confirmed in a repeated-measures ANOVA, $F(4, 20) =$
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4 7.72, $p < .01$, $\eta^2 = .61$, and four pairwise comparisons comparing ratings for gravel relative to
5 each of the other four surfaces (paved: $t(5) = 5.47$, $p < .01$; dirt: $t(5) = 6.70$, $p < .01$; grassy:
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9 $t(5) = 4.57$, $p < .01$; cobblestone: $t(5) = 3.97$, $p < .01$).

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11 *Audio Files.* Four sound files were created, two using footsteps (one transitioning
12 from run to walk, one from walk to run) and two using metronome pulses (one transitioning
13 from fast to slow, one from slow to fast). The footsteps were recorded using a digital
14 recording device and microphone as an experimenter walked over a gravel surface. For the
15 walking sound, the experimenter was guided by a metronome at 1 pulse per second,
16 corresponding to 1 footstep per second walking pace; for running, the metronome was set at
17 3 pulses per second, corresponding to 3 footsteps per second running pace. The pace of
18 footstep sounds was verified and adjusted as necessary using the freely-available Audacity
19 software (version 1.2.6; <http://audacity.sourceforge.net>). This same software was used to
20 generate the metronome sound files, one slow (1 pulse/second) and one fast (3
21 pulses/second), at similar average decibel levels to the footstep sounds. Six naïve pilot study
22 participants were able to identify the gravel audio files as walking over a “gravel” or “rocky”
23 surface (through verbal report within the first 5 seconds of listening).

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43 *Memory Tests.* A statement verification task included 20 trials (see Appendix B)
44 assessing knowledge directly (verbatim) and indirectly (inference) imparted by the text (see
45 Taylor & Tversky, 1992). Four statements tested verbatim locative knowledge by presenting
46 spatial sentences from the original texts (e.g., *The northern border is made up of the White*
47 *Mountain range*), and four tested verbatim non-locative knowledge by presenting non-spatial
48 descriptive sentences from the original texts (e.g., *People often gather at the Store to find out*
49 *the latest town news.*). Twelve additional statements assessed inferencing from both survey
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4 (6) and route (6) perspectives; inference statements required participants to use a mental
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6 representation of the environment, rather than the text itself (e.g., *The Gas Station is east of*
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8 *the river and south of Maple St.*). Half of these statements were presented as correct (eliciting
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10 a TRUE response) and half incorrect (eliciting a FALSE response). Note that when readers
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12 learn via route description, survey inference questions require an inference and a perspective-
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14 switch (and vice-versa).
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18 *Procedure*

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21 *Reading Spatial Descriptions.* Each participant studied all four spatial descriptions,
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23 two presented in the route and two in the survey perspective. Descriptions were presented
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25 one sentence at a time centered on the computer screen (24-pt Arial font), and participants
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27 pressed the spacebar to advance through each sentence (due to length variation some
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29 sentences were presented on a single line and others word-wrapped onto a second line). To
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31 discourage second-pass readings, each sentence was removed from the screen after a
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33 predetermined period of time corresponding to 500msec per word (e.g., a 10-word sentence
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35 removed from the screen after 5 seconds without a response); this rate was chosen based on
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37 research suggesting an approximate average reading speed of 250msec per word (i.e.,
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39 Rayner, 1998). Reading times were automatically recorded using the SuperLab 4.0 software
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41 (Cedrus Inc., 2008). The perspective of each description, and order in which the four
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43 descriptions were presented, were counterbalanced across participants in a Latin square
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45 design. Participants were instructed to read the descriptions at a natural pace, and told that
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47 they would be tested on their memory for the described environment.
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55 *Listening to Sound Files.* While reading, participants used headphones to listen to
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57 footstep sounds for two of the descriptions, and metronome sounds for the other two. The
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4 linking of descriptions to sound types was counterbalanced across participants. Further, half
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6 of the participants ($n = 16$) heard transitions from fast to slow, and the other half heard
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8 transitions from slow to fast. For both transition types, the audio recording was automatically
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10 switched halfway through the reading of the spatial descriptions (by sentence number); in
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12 this way, we were able to assess reading time differences within each participant, and within
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14 each of four descriptions, two survey and two route.
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19 *Testing.* Participants were tested following each description. Testing involved
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21 presenting 20 trials in random order one at a time in the center of the computer monitor. Each
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23 trial was self-paced and required a *true* or *false* response using keys labeled as such (C and
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25 M, respectively). Participants were instructed to verify each statement as quickly as possible
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27 without compromising accuracy.
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30 31 Results

32 33 *Reading time.*

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36 *Scoring & Analysis.* We divided reading time for each description sentence by the
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38 number of syllables in the sentence, and then averaged the reading time per syllable within
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40 each of the two description perspectives, sound types, and sound speeds. Outliers beyond 2.5
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42 standard deviations of each individual's mean reading times were removed from subsequent
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44 analyses (comprising 2.1% of the data). We performed a 2(description perspective: route,
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46 survey) x 2(sound type: footstep, metronome) x 2 (sound speed: fast, slow) repeated-
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48 measures ANOVA on average reading times (in msec per syllable), and followed-up this test
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50 with planned comparisons.
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56 *Results.* The results of the three-way ANOVA are detailed in Table 1. To follow-up
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58 on the three-way interaction between description perspective, sound type, and sound speed,
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4 we performed two 2x2 simple effects ANOVAs, one for the survey and one for route
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6 perspective. In the survey perspective, there was a Sound Type by Sound Speed interaction,
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8 $F(1,31) = 4.75, p < .05, \eta^2 = .13$ (see Figure 1). Planned comparisons within the survey
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10 perspective revealed faster reading times when listening to fast versus slow metronome
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12 sounds, $t(31) = 2.41, p < .05$, but this effect was not found for footstep sounds, $t(31) = .15, p$
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14 $> .05$. In the route perspective, there was no significant Sound Type by Sound Speed
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16 interaction, $F(1,31) = .487, p > .05, \eta^2 = .02$; that is, both the metronome and footstep sounds
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18 produced reading time differences in the same direction. Planned comparisons within the
19
20 route perspective revealed faster reading times when listening to fast versus slow footstep
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22 sounds, $t(31) = 4.34, p < .01$, and fast versus slow metronome sounds, $t(31) = 2.17, p < .05$.

23 24 25 26 27 28 *Test Performance.*

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31 *Scoring & Analysis.* We averaged accuracy and response times (to correct
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33 verification) for each of the four statement types (verbatim locative, verbatim non-locative,
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35 inference survey, inference route) within each of the two description perspectives, and within
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37 each of the two sound types (footsteps, metronome). Response time outliers (comprising
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39 1.8% of the data) were removed as with reading time. We performed 2(Description
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41 Perspective: route, survey) x 2(Sound Type: footstep, metronome) x 2(Statement Type:
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43 spatial, non-spatial *or* within-perspective, across-perspective) repeated-measures ANOVAs
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45 on accuracy and response time data.
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51 *Verbatim Verification, Accuracy.* Verbatim statements were derived directly from the
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53 text and were either spatial or non-spatial in nature; these statements index recognition
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55 memory for previously-viewed sentences. We performed a 2(Description Perspective: route,
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57 survey) x 2(Sound Type: footstep, metronome) x 2(Statement Type: spatial, non-spatial)
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4 repeated measures ANOVA. We found a main effect of Statement Type, indicating higher
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6 accuracy during non-spatial ($M = .92$, $SE = .02$) relative to spatial ($M = .86$, $SE = .02$)
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8 statement verifications, $F(1, 31) = 7.33$, $p < .05$, $\eta^2 = .04$, a rather common finding with
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10 statement verification tasks (Brunyé & Taylor, 2008a, 2008b). There were no other main or
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12 interactive effects (all p 's $> .05$), indicating that verbatim statement verification accuracy did
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14 not vary as a function of Description Perspective or Sound Type either directly or
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19 interactively.

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21 *Verbatim Verification, Response Times.* Analyses were performed as with accuracy
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23 data. We found a main effect of Statement Type, indicating faster response times to non-
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25 spatial ($M = 3.85$ sec, $SE = .22$) relative to spatial ($M = 5.47$ sec, $SE = .20$) statement
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27 verifications, $F(1, 31) = 41.13$, $p < .01$, $\eta^2 = .27$. As with accuracy, there were no other main
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29 or interactive effects (all p 's $> .05$).
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33 *Inferencing, Accuracy.* Inference statement verification required participants to apply
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35 a mental model of the environment and were presented either within or outside of the learned
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37 perspective. Inference questions are a common method for assessing whether readers are
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39 progressing beyond the surface and propositional features of a text (van Dijk & Kintch,
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41 1982), and for assessing perspective-switching performance (Brunyé & Taylor, 2008a,
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43 2008b; Brunyé et al., 2008; Taylor & Tversky, 1992). We performed a 2(Description
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45 Perspective: route, survey) x 2(Sound Type: footstep, metronome) x 2(Statement Type:
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47 within-perspective, across-perspective) repeated measures ANOVA on accuracy data. This
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49 test revealed a main effect of Statement Type, with higher accuracy to within- ($M = .70$, $SE =$
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51 $.04$) relative to across-perspective ($M = .65$, $SE = .04$) statement verifications, $F(1, 31) =$
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53 6.86 , $p < .05$, $\eta^2 = .02$, and a three-way interaction between Description Perspective, Sound
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4 Type, and Statement Type, $F(1, 31) = 4.55, p < .05, \eta^2 = .01$. To break down this three-way
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6 interaction, we performed separate 2(Description Perspective: route, survey) x 2(Sound
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8 Type: footstep, metronome) ANOVAs, one for within- and one for across-perspective
9
10 inference accuracy.
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14 For within-perspective inferences, we replicated earlier work using single-pass
15
16 reading of spatial descriptions (Brunyé & Taylor, 2008a): a main effect of Description
17
18 Perspective revealed higher accuracy following survey ($M = .73, SE = .03$) relative to route
19
20 ($M = .64, SE = .03$) descriptions, $F(1,31) = 7.81, p < .01, \eta^2 = .2$. For across-perspective
21
22 inferences (requiring a perspective switch), there was a significant Description Perspective
23
24 by Sound Type interaction, $F(1,31) = 4.29, p < .05, \eta^2 = .12$; two planned comparisons
25
26 revealed that in the route perspective, footsteps led to marginally lower accuracy ($M = .59,$
27
28 $SE = .04$) relative to metronome pulses ($M = .69, SE = .04, t(31) = 1.84, p = .07$, but in the
29
30 survey perspective there was no difference between the two sound types (footsteps: $M = .68,$
31
32 $SE = .04$, metronome: $M = .65, SE = .05, t(31) = .56, p > .10$. Thus, there is some evidence
33
34 that listening to footsteps during route description reading can lead to perspective-specificity
35
36 in memory; that is, whereas within-perspective inferencing was not affected by listening to
37
38 footsteps during route description reading, across-perspective inferencing was somewhat
39
40 impaired.
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48 *Inferencing, Response Times.* As with accuracy data, we performed a three-way
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50 2(Description Perspective: route, survey) x 2(Sound Type: footstep, metronome) x
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52 2(Statement Type: within-perspective, across-perspective) repeated measures ANOVA on
53
54 response time data. This test revealed a main effect of Statement Type, with faster response
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56 times to within- ($M = 5.59$ sec, $SE = .32$) relative to across-perspective ($M = 5.92$ sec, $SE =$
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4 .31) statement verifications, $F(1, 28) = 6.26, p < .05, \eta^2 = .01$. There were no other main or
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7 interactive effects (p 's $> .05$).

8 9 Discussion

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11 Experiment 1 provides evidence that variably-paced sounds can guide language
12 comprehension by altering the speed with which readers progress through spatial
13
14 descriptions. As expected, increasing the speed of metronome pulses produced faster reading
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16 times across both description perspectives; in contrast, increasing the speed of footstep
17
18 sounds only produced faster reading times with the route perspective. With metronome
19
20 pulses, the reading time effects are likely due to a sense of urgency during reading, with
21
22 faster beeps speeding overall reading times. With footsteps, we suggest that the inherently
23
24 sensorimotor qualities of these sounds guided mental simulation of movement through an
25
26 environment, thus affecting the reading of route but not survey descriptions. As a result,
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28 altering footstep pace led to corresponding modulation of reading times while participants
29
30 mentally simulated a journey through the environment.
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38 Why did footsteps fail to modulate reading times with survey descriptions? This
39
40 pattern is similar to the *irrelevant sound effect*, typified by decreased performance on a
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42 variety of working memory and long-term memory tasks when performed under the
43
44 influence of extraneous auditory information (cf., Jones & Macken, 1993; Jones & Tremblay,
45
46 2000). It is likely that the sensorimotor information provided by the footsteps encouraged an
47
48 embedded perspective. This perspective, however, was incongruent with the perspective
49
50 promoted by the survey description. The conflict between the visual and auditory information
51
52 sources likely slowed reading times enough to counteract any facilitative effects of increased
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54 pace cues; we will further examine the source of this effect in the general discussion. This
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4 result provides convincing evidence that readers differentially embody survey and route
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6 descriptions.
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9 Memory test performance complements the reading time results by providing some
10 evidence that readers embody route descriptions to a greater extent than survey descriptions.
11 Specifically, when route descriptions were coupled with footstep sounds, there was a reduced
12 ability for participants to inference in the survey perspective. This finding adds to a growing
13 body of work suggesting that the mental representations resulting from limited experience
14 with route descriptions are rather bound to the perspective characterizing this experience
15 (Brunyé et al., 2008; Brunyé & Taylor, 2008a; Shelton & McNamara, 2004). We add to this
16 literature by demonstrating that increasing the level of embodiment during route description
17 reading by promoting multi-modal mental simulation from a ground-level perspective can
18 further promote perspective-specificity in memory. The greater than chance performance
19 with within-perspective inferencing suggests that participants who read route descriptions
20 while listening to footstep sounds were comprehending the descriptions and able to think
21 about the environment from a ground-level perspective. Only when they were tasked to
22 switch perspectives was performance impaired.
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43 Experiment 2

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45 Our first experiment demonstrated that movement sounds differentially modulate
46 participants' reading speed as a function of description perspective. There was also evidence
47 that spatial memory can be shaped by these sounds, given the perspective specificity found
48 when route descriptions were coupled with footsteps. Our second experiment was designed
49 to further test whether the eventuating memory representations following route and survey
50 description learning are shaped by the types of mental simulations people perform during
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4 reading. The present experiment was motivated by a body of work demonstrating that
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7 people's perceptions of spatial distance can be calibrated by locomotion (e.g., Iachini &
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9 Guisberti, 2004; Rieser, Pick, Ashmead, & Garing, 1995; Waller & Richardson, 2008). For
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11 instance, when participants run at a speed faster than the surrounding environmental flow
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13 they tend to subsequently overestimate distances in the environment; in contrast, when
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15 participants run at a speed slower than the environmental flow they tend to subsequently
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17 underestimate these same distances (Rieser et al., 1995). If listening to footsteps indeed
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19 encourages the mental simulation of movement through an environment while participants
20
21 read route descriptions, then faster footstep sounds should lead readers to represent greater
22
23 distances between landmarks. That is, mentally simulating a running pace through an
24
25 environment should lead readers to represent farther distances between landmarks than when
26
27 mentally simulating a slow walk (given a constant learning speed). This is because with a fast
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29 relative to slow pace sound, participants hear more footsteps within an identical time frame.
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36 Most spatial descriptions convey categorical rather than metric information, meaning
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38 that any distances that can be generated from a spatial mental model are derived primarily
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40 from pragmatics (i.e., knowledge of the approximate size of most convention centers) rather
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42 than explicit mention. Despite this, readers typically can generate coarse distance information
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44 from spatial mental models. Denis and Zimmer (1992) had participants learn either a map or
45
46 survey spatial description and then perform, among other tasks, distance estimations.
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48 Performance on this task was equivalent following either map study or description reading,
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50 suggesting structural isomorphism between memories formed from either format, but also
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52 demonstrating that spatial descriptions can provide adequate information for readers to make
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54 judgments regarding environmental scale (see also, Cocude, Mellet, & Denis, 1999; Denis,
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4 Goncalves, & Memmi, 1995). More recent work supports this notion by demonstrating that
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6 accurate metric information can be derived from both route and survey spatial descriptions
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8 even when they contain no explicit reference to distance (Noordzij & Postma, 2005).
9

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11 In the present study participants read spatial descriptions at a prescribed pace while
12
13 listening to consistently slow or fast footsteps or metronome sounds. They then completed
14
15 two memory tests. Whereas most of the aforementioned studies have used relative distance
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17 estimations, such as asking whether a second distance (e.g., X to Y) is shorter or longer than a
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19 first distance (e.g., X to Z)¹, we included two tasks that could provide an indication of
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21 absolute rather than relative scaling differences. The first task involved sketchmap drawing,
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23 which allowed us to look at whether participants would draw differently-sized inter-landmark
24
25 distances as a function of perceived movement speed. The second task was done after the
26
27 participant had completed drawing and involved denoting the metric scale of their
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29 sketchmap. This task allowed us to assess the participants' conceptualization of
30
31 environmental scale as a function of whether they listened to fast versus slow footstep or
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33 metronome sounds.
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41 If footsteps encourage embodied mental simulation of movement through an
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43 environment presented in a route perspective, then faster footsteps should lead participants to
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45 imagine faster and thus lengthier movement through an environment. If this the case, because
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47 the pace of the sentences remains constant, participants may perceive covering more ground
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49 with fast versus slow footsteps and thus represent the environments as larger than they would
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51 while listening to slow footsteps. We suggest that metronome pulses do not necessarily pace
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53 movement through an environment but rather increased reading speed in Experiment 1 only
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59 ¹ While this task is excellent for determining whether spatial memories contain accurate relative metric
60 information, it does not provide information regarding absolute environmental scale.
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4 as a function of pacing. Thus, we do not expect metronome pulses to elicit an effect on
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6 spatial memory. If these hypotheses are supported it would strengthen the notion that readers
7
8 can use sensorimotor information to guide mental simulations through environments with
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10 route but not survey descriptions.
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13 14 Method

15 16 *Participants & Design*

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18 A total of 48 Tufts University undergraduates (25 male; age $M = 19.8$, $SD = .96$)
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20 participated for monetary compensation. We used a mixed design, with sound type (2:
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22 footstep, metronome) and sound speed (2: fast, slow) as within-participants factors, and
23
24 description perspective (2: route, survey) as a between-participants factor. Unlike Experiment
25
26 1, sound speed was manipulated across rather than within descriptions. We used scale
27
28 estimation and sketchmap drawing to assess participants' memory for the described
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30 environments.
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35 36 *Materials*

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38 *Spatial Descriptions.* We used identical descriptions to those used in Experiment 1.
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41 *Audio Files.* Sound files were created using the same footstep sounds as in
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43 Experiment 1. However, because the sound files no longer change within-description, the
44
45 four sound files did not have pace transitions (i.e., consistently walking, running, slow
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47 metronome, or fast metronome).
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51 *Memory Test.* We used a sketchmap drawing task and asked participants to indicate
52
53 map scale. Maps were drawn on 11" x 11" pieces of plain white paper. A single question
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55 asked participants to indicate their drawn environment's scale relative to a 1" line, using a 5-
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57 point Likert response scale. The scale anchors were developed separately for each
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4 environment by conducting a pilot study ($n = 17$) during which participants learned each of
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6 the four environments (experimenter-paced, sentence-by-sentence) and completed a map
7
8 drawing and open-ended scale estimation task (i.e., 1" = ___ feet/miles). The median
9
10 distance provided on the open-ended scale was then used to establish central Likert scale
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12 anchors for each environment. For instance, the town environment elicited responses that
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14 ranged from 1" = 100ft. to 1" = 10,560ft. ($M = 3205.88$, $SD = 3403.53$), and the median
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16 response in miles (2640 feet, or $\frac{1}{2}$ mile) was used as the central anchor. The lower and upper
17
18 anchors of each Likert scale were determined by dividing the central anchor in half (lower
19
20 anchor) and multiplying the central anchor by 1.5 (upper), respectively. The town and resort
21
22 anchors were provided in miles (range from .25 to .75 mile, and .5 to 1.5 miles, respectively),
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24 and the zoo and convention center anchors were provided in feet (range from 50 to 150 feet,
25
26 and 15 to 45 feet, respectively)². Participants were asked to indicate the scale of their drawn
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28 map (relative to a provided 1" reference line) by placing a tick mark anywhere on the 5-point
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30 Likert scale.

31 32 33 34 35 36 37 38 *Procedure*

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41 *Reading Spatial Descriptions.* Descriptions were presented one sentence at a time
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43 centered on the computer screen. Each sentence was presented at rates established in earlier
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45 work (Brunyé & Taylor, 2008b); average presentation time per sentence was 6.14 seconds
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47 (upper limit 9.86 sec, lower limit 2.51 sec, $SD = 1.62$ sec). These presentation rates
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49 approximate 300msec/word (i.e., Sereno & Rayner, 2003); presentation rate was held
50
51 constant in an effort to ensure isolation of sound type and speed effects on spatial memory.
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58 ² We chose to use the most appropriate (and frequently used in pilot ratings) scale given the environment size,
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60 rather than using a consistent scale across large- (resort, town) and small-scale (zoo, convention center)
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62 environments.
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4 Participants were instructed to read the descriptions and told that they would be tested on
5
6 their memory for the described environment.
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9 *Listening to Sound Files.* While reading, participants listened to footstep sounds for
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11 two of the descriptions (one fast, one slow), and metronome sounds for the other two (one
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13 fast, one slow). The linking of descriptions to sound types and sound speeds was
14
15 counterbalanced across participants.
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19 *Testing.* Participants were tested following each description. Testing involved
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21 presenting participants with a sheet of paper and providing them with up to 5 minutes to
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23 draw. After drawing, they were asked to indicate map scale relative to a 1” reference line by
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25 using a provided Likert scale.
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28 Results

29 *Map Drawing.*

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33 *Scoring & Analysis.* Maps were scored in three ways. First, to assess overall landmark
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35 drawing performance we examined the proportion of landmark names correctly recalled.
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37 Second, we assessed the overall accuracy of the spatial configuration of landmarks by
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39 examining relative landmark location accuracy (i.e., Brunyé & Taylor, 2008a, 2008b).
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41 Relative landmark location assesses correspondence with comparisons derived from survey
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43 (e.g., Is Maple St. south of the White Mountains?) and route (e.g., Is Maple St. on the left as
44
45 you approach the White Mountains on Mountain Road?) descriptions. Whereas most (98.5%)
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47 drawn landmarks were labeled, it was not a requirement towards inclusion in this scoring
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49 procedure; for instance, landmarks depicted in generally the correct location and shape were
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51 included towards relative landmark location judgments. Third, we averaged the mean
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53 distance between all landmark pairs drawn on the sketchmaps (using the same landmark
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4 inclusion criteria as with relative landmark location) and then divided this number by the
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6 overall size of the drawn environment (at the diagonals); this method allowed us to assess the
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8 distance between landmarks relative to the limits of the drawn environment, which accounts
9
10 for variation in drawing style (i.e., some drew overall small and some overall large maps).
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14 Data from all three scoring procedures were submitted to three separate 2(Sound Type:
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16 footstep, metronome) x 2(Sound Speed: fast, slow) x 2(Description Perspective: route,
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18 survey) mixed models ANOVAs.
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21 *Proportion of Landmarks Recalled.* A main effect of Description Perspective revealed
22
23 a greater proportion of landmarks recalled following the survey ($M = .43$, $SE = .02$) relative
24
25 to the route ($M = .34$, $SE = .02$) perspective, $F(1, 46) = 8.27$, $p < .01$, $\eta^2 = .15$. There were no
26
27 other main or interactive effects (all p 's $> .05$).
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31 *Relative Landmark Location Accuracy.* A main effect of Description Perspective
32
33 revealed higher relative landmark location accuracy following the survey ($M = .72$, $SE = .02$)
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35 relative to the route ($M = .67$, $SE = .02$) perspective, $F(1, 46) = 5.59$, $p < .05$, $\eta^2 = .11$. As
36
37 with the recall data, there were no other main or interactive effects (all p 's $> .05$).
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41 *Distance Between Landmarks.* A marginal three-way interaction between sound type,
42
43 sound speed, and description perspective revealed that sound type and sound speed may
44
45 interact within one of the two description perspective groups, $F(1, 46) = 2.92$, $p < .10$, $\eta^2 =$
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47 $.06$. Within the survey description, sound type did not interact with sound speed, $F(1, 23) =$
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49 $.03$, $p > .05$. The two variables interacted within the route description group, $F(1, 23) = 4.16$,
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51 $p < .05$, $\eta^2 = .15$. Faster footsteps led to larger distances drawn between landmarks on
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53 sketchmaps ($M = .40$, $SD = .11$) relative to slow footsteps ($M = .33$, $SD = .10$), $t(23) = 2.19$, p
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55 $< .05$, $d = .44$, but this effect was not found with metronome sounds, $t(23) = .46$, $p > .05$.
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4 Overall, participants drew larger distances between landmarks after listening to fast relative
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7 to slow footsteps, but only after reading the route perspective.

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9 *Environmental Scale.*

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11 *Scoring & Analysis.* We averaged the mean judgments of environment scale (from 1
12
13 to 5) provided by participants, within each of the three independent variables. We performed
14
15 a 2(sound type: footstep, metronome) x 2(sound speed: slow, fast) x 2(description
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17 perspective: survey, route) mixed model ANOVA on these data.
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21 *Results.* A three-way interaction between sound type, sound speed, and description
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23 perspective revealed that sound type and sound speed only interacted within one of the two
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25 description perspective groups, $F(1, 46) = 4.15, p < .05, \eta^2 = .03$. Within the survey
26
27 description, sound type did not interact with sound speed, $F(1, 23) = .39, p > .05$. As depicted
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29 in Figure 2, the two variables interacted within the route description group, $F(1, 23) = 6.01, p$
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31 $< .05, \eta^2 = .07$. Faster footsteps led to increased judgments of environmental scale relative to
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33 slow footsteps, $t(23) = 3.39, p < .01, d = .69$, but this effect was not found with metronome
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35 sounds, $t(23) = .25, p > .05$. Overall, participants judged environments to be larger in scale
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37 after listening to fast relative to slow footsteps, but only after reading the route perspective.
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43 Discussion

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45 Experiment 2 demonstrates that mental representations of environmental scale can be
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47 modulated by simulated locomotion speed. In this case, increased footstep pace led readers to
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49 imagine traversing farther distances between landmarks during route but not survey
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51 description reading. Two pieces of evidence supported this finding. First, participants tended
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53 to draw overall larger distances between landmarks on sketchmaps when they read route
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55 descriptions while listening to fast relative to slow footstep sounds. It seems to be the case
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4 that readers calibrated their estimates of distance based upon the speed with which they
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6 mentally simulated movement through an environment. This finding supports the notion that
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8 readers actively immerse themselves in narrative worlds and can incorporate multi-modal
9
10 information into these mental simulations (e.g., Glenberg & Kaschak, 2002, 2003). The
11
12 second piece of evidence was that participants' metric estimates of environmental scale were
13
14 also affected by implied movement speed during route description reading. Taken together,
15
16 these results support work demonstrating the calibration of distance perception as a function
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18 of locomotion (i.e., Rieser et al., 1995), and uniquely extend it to spatial memories acquired
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20 during discourse comprehension.
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25 26 General Discussion

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28 In the present experiments, we set out to assess the extent to which readers can use
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30 multi-modal information to guide mental simulations and memory of described
31
32 environments. Participants read survey or route spatial descriptions while listening to sounds
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34 that either contained (footsteps) or did not contain (metronome) sensorimotor information.
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36 We asked whether the inherent sensorimotor qualities of footstep sounds could modulate
37
38 readers' comprehension and memory for spatial information. Two experiments demonstrated
39
40 that this is the case. Experiment 1 showed that movement sounds can guide readers' mental
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42 simulations of locomotion and affect their comprehension of spatial descriptions and
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44 Experiment 2 demonstrated that this can extend to lasting effects on memory. Our results
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46 point to the importance of mental simulations in shaping understanding during reading and
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48 influencing how we ultimately understand spatial information acquired from descriptions.
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55 A trademark benefit of having formed a flexible spatial mental model is the ability to
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57 quickly and accurately inference in a perspective incongruent with that presented during
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4 learning. For instance, learning in the route perspective and subsequently making Euclidean
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6 determinations of landmark relations, or learning in the survey perspective and providing
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8 route instructions to a tourist. Controversy currently exists within the spatial cognition
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10 literature with regard to the flexible versus invariant nature of spatial memory resulting from
11
12 various input types (e.g., Avraamides, Loomis, Klatzky, & Golledge, 2004; Brunyé et al.,
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14 2008; De Beni et al., 2005; Ishikawa & Montello, 2006; Denis, 2008; Klatzky, Lipka,
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16 Loomis, & Golledge, 2003; Lee & Tversky, 2001; Levinson, 2003; Noordzij, Van der Lubbe,
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18 & Postma, 2005, 2006; Noordzij, Zuidhoek, & Postma, 2006; Pazzaglia et al., 2007; Péruch,
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20 Chabanne, Nese, Thinus-Blanc, & Denis, 2006; Shelton & McNamara, 2004; van Asselen,
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22 Fritschy, & Postma, 2006). Indeed some have found results suggesting that spatial memory
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24 need not maintain the perspective provided by the learning experience (e.g., Brunyé &
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26 Taylor, 2008a; Denis, 2008; Lee & Tversky, 2001; Noordzij & Postma, 2005; Taylor &
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28 Tversky, 1992a), whereas other have found results suggesting that spatial memory is
29
30 experientially grounded and maintains the learned perspective (e.g., Lee & Tversky, 2005;
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32 Péruch, et al., 2006; Schneider & Taylor, 1999; Shelton & McNamara, 2004). Many of these
33
34 differences are likely attributable to variation in environment type and scale, extent of
35
36 learning, presentation format, learning goals, task instructions, and individual differences
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38 (Bosco, Sardone, Scalisi, & Longoni, 1996; Brunyé & Taylor, in press; Brunyé & Taylor,
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40 2008a,b; Denis, 2008; Gyselinck, de Beni, Pazzaglia, Meneghetti, & Mondoloni, 2007;
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42 Hegarty & Waller, 2005; Ishikawa & Montello, 2006; Noordzij et al., 2005, 2006; Prestopnik
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44 & Roskos-Ewoldsen, 2000; Taylor, Naylor, & Chechile, 1999; van Asselen et al., 2006). We
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46 add to this growing body of literature by uniquely demonstrating that encouraging
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48 embodiment via multi-modal simulation during route description reading can impose later
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4 limitations on inference generation across perspectives. That is, a higher degree of immersion
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6 in described environments leads to memory that is experientially grounded and bound to the
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8 learned perspective. However, without reinforcing such ground-level immersion, readers
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10 show a generally high degree of perspective flexibility. It is clear that spatial memory cannot
11
12 be considered invariably perspective-specific or perspective-flexible; indeed recent two-
13
14 system spatial memory theories posit both egocentric (first-person) and allocentric (external
15
16 perspective) representations existing in parallel (Burgess, 2006).
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21 Prior work in our own and others' laboratories has consistently demonstrated the
22
23 relatively demanding nature of learning from route relative to survey descriptions (e.g.,
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25 Brunyé & Taylor, 2008a; Noordzij, M. L., Zuidhoek, S., & Postma, A., 2006; Pazzaglia et
26
27 al., 2007). The present work suggests that these effects are at least partially due to a relatively
28
29 vivid sense of 'being there' evoked by route versus survey descriptions. Strong embodied
30
31 theories predict that mentally simulating described information is a critical component to
32
33 language comprehension in general (Barsalou, 2005, 2008; Glenberg, 2007). Developing rich
34
35 mental simulations of actions within described space may not be necessary for
36
37 comprehension (i.e., during survey description reading), but has been identified as important
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39 in several regards. First, mental simulations of described information can prepare readers for
40
41 real action by unconsciously priming action representations (Glenberg & Kaschak, 2002,
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43 2003). Second, other work demonstrates that ambiguous language can be effectively resolved
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45 through imagery formation (Bergen & Chang, 2005). Not surprisingly many modern theories
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47 of language comprehension strongly emphasize the importance of grounding mental
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49 representation in the senses.
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4 Related work has further suggested that mental simulations can help readers develop
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6 complex inferences about described space, and ultimately develop flexible situation models
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8 (Brunyé & Taylor, 2008a; Zwaan, 1999, 2004). The present work, however, suggests that
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10 developing rich mental simulations during route description reading can produce the opposite
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12 effect; these mental simulations can promote perspective specificity in memory and limit the
13
14 flexibility of a reader's spatial mental model. Such a result may be advantageous when a
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16 reader is tasked to solve spatial problems only from an immersed ground-level perspective,
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18 but disadvantageous when both egocentric and allocentric representations need to be
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20 recruited during relatively naturalistic tasks (e.g., finding novel shortcuts, route re-planning
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22 due to a detour). We add to the extant literature by demonstrating that under certain
23
24 conditions readers can develop perspective-specific spatial models (i.e., Shelton &
25
26 McNamara, 2004), and that the immersion promoted by rich mental simulations of route
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28 descriptions may in fact prove harmful for flexible spatial performance.
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36 Recent work has demonstrated that the extent to which people embody described
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38 events is contingent upon several characteristics of a text, such as pronominal reference
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40 (Brunyé et al., 2009; Ruby & Decety, 2001), and literal versus metaphorical meaning
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42 (Bergen, Lindsay, Matlock, & Narayanan, 2007). We add to this growing body of literature
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44 to suggest that the degree of 'embodied' understanding is contingent upon not only the
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46 information provided by a text, but also contextual multimodal input that may or may not be
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48 relevant to comprehension. Indeed survey descriptions may be most amenable to forming
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50 mental imagery that takes an outside 'observer' perspective, taking on a form like a mental
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52 map. As such any sense of ground-level 'presence' during survey description reading runs
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54 counter to the linguistically-specified perspective; thus, listening to footsteps during survey
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4 description reading promotes a perspective that directly contradicts the text. The fact that
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7 speeded footstep sounds did not promote faster survey description reading suggests that
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9 embodied spatial description reading is partially governed by a judgment and top-down
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11 influence of informational relevance. Indeed a reader only deems information of particular
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13 relevance when it is cognitively advantageous and does not require a disproportionately high
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15 degree of cognitive effort (i.e., Relevance theory; Sperber & Wilson, 1986; Sperber &
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17 Wilson, 1995). Relevance theory contends that readers will only incur the processing cost of
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19 integrating additional information if they have an expectation of a cognitive advantage; given
20
21 the present results, we suggest that the embodiment of multimodal information into a
22
23 developing mental model may not be spontaneous and automatic. Given that footsteps
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25 directly contrast the perspectives characterizing the mental imagery formed during survey
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27 description reading, and their integration would require a high degree of processing resources
28
29 (i.e., towards mental rotation and adopting new perspectives), they are potentially deemed of
30
31 little relevance to the reading task. Metronome pulses, in contrast, do not contradict a
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33 linguistically-specified perspective and are found to facilitate survey description reading.
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35 Route descriptions directly address the reader as the subject of sentences and describe first-
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37 person movement through an environment at the ground level, making them most amenable
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39 to immersed experience, and able to take advantage of the highly relevant footstep sounds to
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41 pace reading speed. It appears to be the case that the structure and content of language, along
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43 with the knowledge and expectations of the reader, can constrain the multi-modal nature of
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45 mental simulations (see also Bergen et al., 2007; Ditman et al., in press; Feldman, 2006;
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47 Kaschak and Glenberg, 2000).

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4 In sum, the present work provides unique evidence regarding how language can
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6 integrate with multimodal information sources to guide and constrain the nature of mental
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8 simulations. We find that mental simulations of spatial descriptions can be shaped by
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10 accompanying auditory information, and such effects can lead to biases in how readers
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12 structure space. Indeed it appears to be the case that readers use auditory information to guide
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14 mental simulations, and that the processes governing perception of spatial distance in the real
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16 world can be applied to language comprehension. We hope further research will assess the
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18 influences of additional sensory modalities such as olfaction, taste, and touch. Only by
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20 examining the full scope of human sensory capability can we attempt to understand the
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22 extent to which mental simulations during language comprehension truly capture the richness
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24 of direct perception and action.
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Author Note

The opinions expressed herein are those of the authors and not necessarily of the United States Army. Portions of these results were presented by T.T.B. at the International Congress of Psychology in Berlin, Germany (2008).

Table 1. *Experiment 1 ANOVA Results for Reading Time*

Factor(s)	Result
Description Perspective	$F(1,31) = .092, p > .05, \eta^2 < .01$
Sound Type	$F(1,31) = .002, p > .05, \eta^2 < .01$
Sound Speed	$F(1,31) = 10.7, p < .01, \eta^2 = .26$
Description Perspective x Sound Type	$F(1,31) = .587, p > .05, \eta^2 = .02$
Description Perspective x Sound Speed	$F(1,31) = 4.95, p < .05, \eta^2 = .14$
Sound Type x Sound Speed	$F(1,31) = .478, p > .05, \eta^2 = .02$
Description Perspective x Sound Type x Sound Speed	$F(1,31) = 5.01, p < .05, \eta^2 = .14$

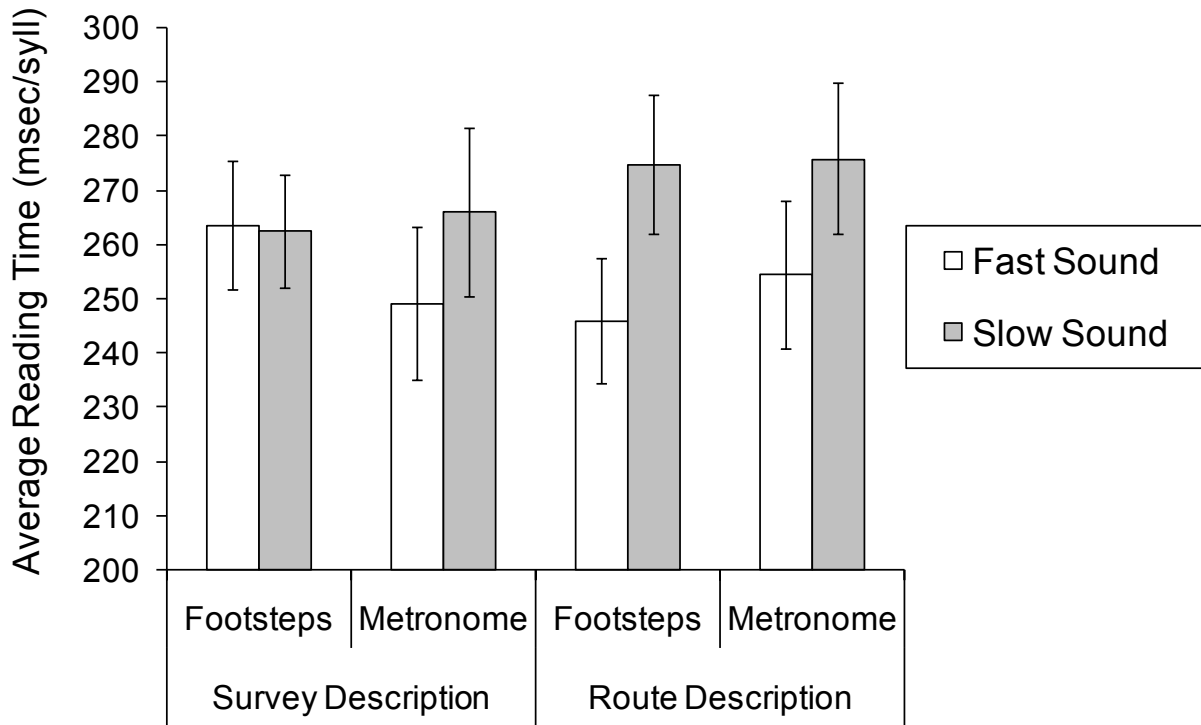
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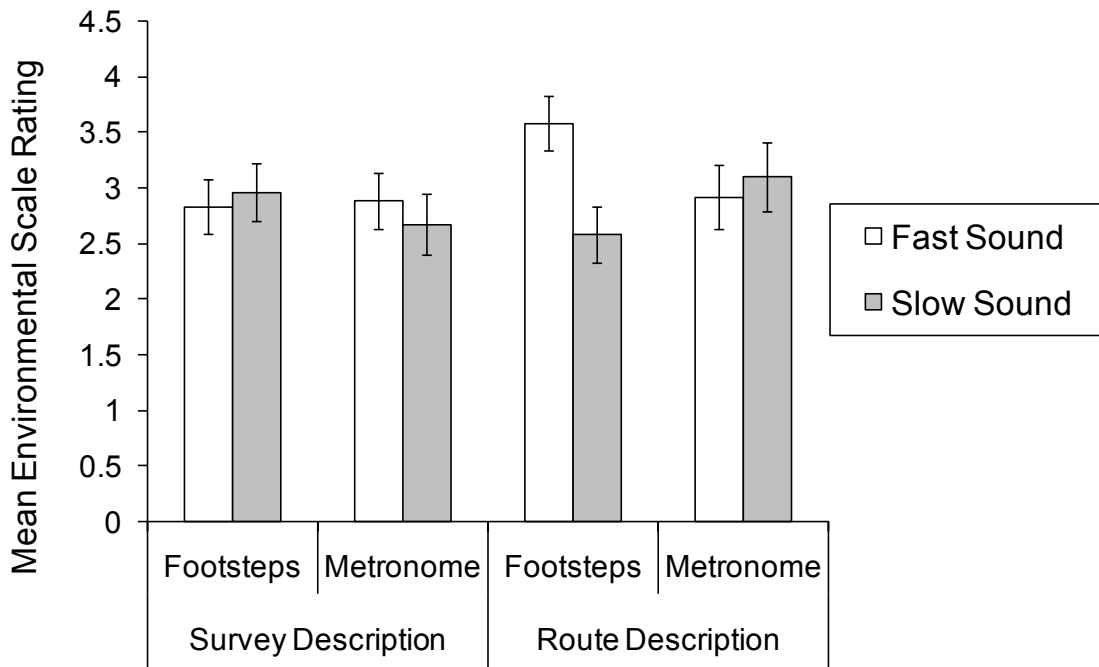
Figure Captions

Figure 1. Experiment 1 average reading time (presented as mean milliseconds per syllable) as a function of spatial description perspective (survey/route), sound type (footstep/metronome), and sound pace (fast/slow).

Figure 2. Experiment 2 mean environmental scale rating, as a function of spatial description perspective (survey/route), sound type (footstep/metronome), and sound pace (fast/slow).



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Appendix A. *Survey and Route perspective descriptions for the convention center, zoo, resort, and town environments.*

Convention Center: Survey Perspective

Several companies that manufacture electronics have decided to get together for a convention to show their wares. A large convention center was chosen because its large rectangular floor plan can be easily changed to accommodate the needs of various conventions. The convention center was erected on a vacant gravel parking lot. Temporary wall dividers are used to separate the displays and to form a single entrance to each display. The displays have been grouped according to three categories--Visual Equipment, Personal Computers, and Audio Equipment. The rectangular center section of the building is divided into four displays for the visual equipment. In the northwest corner of the center section, with the entrance facing north, are the Televisions. Like many television displays, the sets are lined up along the walls, all tuned to the same station. In the northeast corner of the center section, with the entrance facing north, are the VCR's. In the southwest corner of the center section, with the entrance facing south, are the 35mm Cameras. In the southeast corner of the center section, with the entrance facing south, are the Movie Cameras. The Movie Cameras are set up to film people as they walk by the display. The remainder of the displays are along the outer, rectangular wall of the Convention Center. The east wall has only one display, the Personal Computers. This display is in the northeast corner and extends for about half of the east wall. There are software samples available for potential customers to test the various computers. Along the north wall are the two Audio Equipment displays--the Stereo Components and the CD Players. Along the north wall, directly west of the Personal Computers, are the Stereo Components. The Stereo Components display includes such items as receivers, turntables, speakers, and tape decks. Directly west of the Stereo Components are the CD Players. In addition to the displays, there are four permanent features of the Convention Center located along the west and south walls--the Cafeteria, the Restrooms, the Office, and the Bulletin Board. Just west of the CD Players, beginning in the northwest corner of the Convention Center and extending for about half of the west wall, is the Cafeteria. The Cafeteria is privately run by a family that leases the space on a permanent basis from the Convention Center. Directly south of the Cafeteria, on the west wall, are the Restrooms. Directly south of the Restrooms, extending from the southwest corner for about a third of the south wall, is the Office. East of the Office, covering about half of the south wall, is the Bulletin Board. The Bulletin Board is used in every convention for the business cards of the participating companies. East of the Bulletin Board, on the east side of the building near the southeast corner, is the entrance.

Convention Center: Route Perspective

Several companies that manufacture electronics have decided to get together for a convention to show their wares. A large convention center was chosen because its large, rectangular floor plan can be easily changed to accommodate the needs of various conventions. The convention center was erected on a vacant gravel parking lot. Temporary wall dividers are used to separate the displays and to form a single entrance to each display. The displays have been grouped according to three categories--Visual Equipment, Personal Computers, and Audio Equipment. You go to the east side of the building near the southeast corner where you find the entrance. As you walk into the building, you see, on your left, a Bulletin Board. The Bulletin Board is used in every convention for the business cards of the participating companies. Continuing straight ahead from the entrance, where the Bulletin Board is on your left, you reach, on your right, the Movie Cameras. The Movie Cameras are set up to film people as they walk by the display. Walking past the Movie Cameras on your right, you see, again on your right, the 35mm Cameras. On your left, stretching into the corner of the building, is the Office. From the Office, you are forced to turn right and you see, to your immediate left, the Restrooms. You continue forward from the Restrooms until you see, on your left stretching into the corner of the building, the Cafeteria. The Cafeteria is privately run by a family that leases the space on a permanent basis from the Convention Center. From the Cafeteria, you walk forward, until you are forced to turn right and you see, to your immediate left, the CD Players. On your right are the Televisions. Like many television displays, the sets are lined up along the walls, all tuned to the same station. You walk past the Televisions, on your right, and continue forward until you see, again on your right, the VCR's. On your left are the Stereo Components. This display includes such items as receivers, turntables, speakers, and tape decks. From the Stereo Components you walk forward until you are forced to turn right and you see, to your immediate left, the Personal Computers. There are software samples available for potential customers to test the various computers. From the Personal Computers, you walk until you reach, on your left, the corridor leading to the entrance of the building.

Zoo: Survey Perspective

The Zoo is a great place to take children on warm, sunny afternoons. It has gravel sidewalks and lots of flowers and trees. The Zoo has five main regions: the Facilities, in the center, and the Large Mammals, the Children's Zoo, the Arctic Animals, and the Primates, in each of four quadrants. Within the Facilities Complex is an information window, a gift shop, and a snack bar. The specialty of the snack bar is a drink called Orange Whip, which is made by mixing orange sherbet and orange juice. In the northwest section of the Zoo are the Large Mammals. There are two cages within the Large Mammals section--the Elephants and the Giraffes. On the west side of the Large Mammals section are the Elephants. There are four African elephants in the cage. On the east side of the Large Mammals section are the Giraffes. The giraffes like to try to stretch their necks even further to eat the leaves on the trees. In the northeast corner of the Zoo, along the north wall, is the entrance. Just west and south of the entrance, inside the gate, is the Ticket Booth. In the northeast section of the Zoo, south of the Ticket Booth, is the Children's Zoo. Children especially like the Children's Zoo, because they can pet the animals. There are two cages within the Children's Zoo--the Ducks' and the Lambs'. On the west side of the Children's Zoo is the Duck Pond. In springtime, when the new ducklings hatch, is the best time to see the Duck Pond. On the east side of this section is the Lamb Petting Area. In the southwest section of the Zoo are the Arctic Animals. There are two cages within the Arctic Animal section--the Penguins and the Polar Bears. On the north side of this section is the Penguin

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4 Building. There are special refrigeration units that keep this building at a comfortable temperature for the Penguins. On the south
5 side of this section are the Polar Bears. The Polar Bears also have special cooling systems. In the southeast section of the Zoo are
6 the Primates. There are two cages within the Primates section--the Chimps and the Baboons. On the north side of the Primate
7 section is the Chimp Show. The chimps have been trained to perform many kinds of tricks including riding unicycles and playing the
8 piano. On the south side of this section is the Baboon Colony.

9 **Zoo: Route Perspective**

10 The Zoo is a great place to take children on warm, sunny afternoons. It has gravel sidewalks and lots of flowers and trees. In the
11 northeast corner of the Zoo, along the north wall, is the entrance. As soon as you enter the Zoo, you see, on your right, the Ticket
12 Booth. The entrance leads you directly into the Children's Zoo. Children especially like this section, because they can pet the
13 animals. Straight in front of you is the Lamb Petting Area. At the Lamb Area, you turn right and walk until you see, on your left, the
14 Duck Pond. In springtime, when the new ducklings hatch, is the best time to see the Duck Pond. You turn left and walk between the
15 Lamb Petting Area, which is on your left, and the Duck Pond, which is on your right. Continuing straight ahead, away from the
16 entrance, you enter the Primate section. In front of you is the Chimp Show. The chimps have been trained to perform many kinds of
17 tricks including riding unicycles and playing the piano. You turn right and walk to the corner of the Chimp Show where you turn left
18 and then walk forward until you come to, on your left, the Baboon Colony. From the Baboon Colony, you turn right and walk into
19 the Arctic Animal section. Continuing forward, you reach the Polar Bears' cage. There are special refrigeration units that keep this
20 building at a comfortable temperature for the polar bears. From the Polar Bears' Cage, you turn right and walk until you see, on your
21 left, the Penguin Building. The penguins also have a special cooling system. You turn left at the corner of the Penguin Building and
22 then walk about half the distance of the building where you turn right and then enter the Large Mammals section. As you enter the
23 Large Mammals section from the Arctic Animals section, you find yourself in front of two cages. Slightly to your left is the Elephant
24 Cage. There are four African elephants in the cage. Slightly to your right is the Giraffe Cage. The giraffes like to try to stretch their
25 necks even further to eat the leaves on the trees. From your position in front of these two cages, you turn right. You walk forward,
26 passing the giraffes on your left, until you reach the Facilities, located to your right and in the center of the Zoo. Within the facilities
27 complex is an information window, a gift shop, and a snack bar. The specialty of the snack bar is a drink called Orange Whip, which
28 is made by mixing orange sherbet and orange juice. You continue forward past the Facilities to find yourself facing the Duck Pond.

29 **Resort: Survey Perspective**

30 The Pigeon Lake resort area is well situated for people who are interested in a variety of outdoor activities, and is entirely comprised
31 of scenic dirt roads with gravel sidewalks. The resort area is bordered by four major landmarks: the National Forest, Matilda Bay,
32 Bay Rd., and the Forest Highway. The eastern border is made up of the National Forest. The National Forest has facilities for
33 camping, hiking, and rock climbing. The southern border is made up of Matilda Bay. Two major roads, Bay Road and the Forest
34 Highway, form the other two borders of the region. Running north-south along the western border of this region is Bay Rd. Bay Rd.
35 is the main access to the many recreational areas on Matilda Bay. Bay Rd. is also the main route in and out of this region. The
36 northern border for the region and the link between Bay Rd. and the National Forest is made up of the Forest Highway. Pigeon Lake
37 is a large recreational lake in the center of the region. There are many activities that center around Pigeon Lake, including boating,
38 water-skiing, and swimming. On the east shore of the lake there is a Swimming Beach. In the busy summer tourist season, there are
39 lifeguards on the beach. At the southernmost point of the lake there is a Fishing Pier and a Boat Launch. Since there is only one
40 boat launch for Pigeon Lake, there is usually quite a bit of traffic near the launch site. Following the rounded outline of the lake is
41 Horseshoe Dr. Horseshoe drive connects with Forest Highway in two places--one west of the National Forest and the other east of
42 Bay Rd. Horseshoe Dr. is the only road that you can take to get into the main resort section of the Pigeon Lake region. There are
43 three small towns within the Pigeon Lake region that all lie along Horseshoe Drive. On the east side of the lake, on the National
44 Forest side of Horseshoe Dr. is the town of Jefferson. Jefferson is the main center for hiking and cycling for the area. On the south
45 side of the lake, midway between Horseshoe Dr. and Matilda Bay is the town of Lincoln. Because of its close proximity to the bay,
46 Lincoln is considered, by tourists, to have the best location in the region. On the west shore of the, between the lake and Horseshoe
47 Dr. is the town of Madison. Madison is directly across the lake from the swimming beach. Madison is the site of the Annual Seafood
48 Festival where the main event is the fishing contest.

49 **Resort: Route Perspective**

50 The Pigeon Lake resort area is well situated for people who are interested in a variety of outdoor activities, and is entirely comprised
51 of scenic dirt roads with gravel sidewalks. To reach the Pigeon Lake region, you walk south along Bay Rd. until you reach, on your
52 left, the point where the Forest Highway dead-ends into Bay Rd. From this intersection, you can see in the distance that Bay Rd.
53 continues to Matilda Bay and its many recreational areas. You turn left onto the Forest Highway and go along until you reach, on
54 your right, Horseshoe Drive. Horseshoe Dr. is the only road that you can take to go into the Pigeon Lake region. Turning right onto
55 Horseshoe Drive, from the Forest Highway, you see, on your left, Pigeon Lake. Pigeon Lake is a large recreational lake in the center
56 of this region. There are many activities that center around Pigeon Lake, including boating, water-skiing, and swimming. After going
57 along Horseshoe Drive for some time, you see, on your left, the small town of Madison. Madison is the site of the Annual Seafood
58 Festival where the main event is the fishing contest. As you continue along Horseshoe Drive, you notice that the road follows the
59 rounded outline of the lake. After you leave Madison, you see, off Horseshoe Dr. on your right, the little town of Lincoln. From your
60 position, only a short distance beyond Lincoln you can see Matilda Bay. Because of its close proximity to the bay, Lincoln is
61 considered, by tourists, to have the best location in the region. From your position with Lincoln on your right, you see, on your left,
62 the Fishing Pier and Boat Launch for Pigeon Lake. Since there is only one boat launch for Pigeon Lake, there is usually quite a bit of
63 traffic near the launch site. Continuing around the shore of the lake on Horseshoe Dr., you walk until you come to the swimming
64 beach and the town of Jefferson. On your left is the swimming beach. In the busy summer tourist season, there are lifeguards on the
65 beach. From your position with the Swimming Beach on your left, you see, on your right, the town of Jefferson. Jefferson is the main
66 center for hiking and cycling in the area. You walk on Horseshoe Dr. until you return to the Forest Highway. To your right, you can
67 see the National Forest. The National Forest has facilities for camping, hiking, and rock climbing. Turning left onto the Forest

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4 Highway, you walk along and again see, on your left, the beginning of Horseshoe Dr. Continuing along the highway, you return to
5 Bay Rd. which leads you out of the region.

6 **Town: Survey Perspective**

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8 One of the largest town fairs and pumpkin festivals in the United States is held each year in the town of Etna. Etna is a typical small
9 New England town with dirt roads and gravel sidewalks. The lay-out of the town has not changed much since it was founded in the
10 1700's. Etna and its surrounding areas are bordered by four major landmarks: the White Mountains, the White River, the River
11 Highway, and Mountain Rd. The northern border is made up of the White Mountain Range. Running north-south along the western
12 border of this region is the White River. The southern border is made up of the River Highway. Along the eastern border, connecting
13 the River Highway to the mountains, is Mountain Rd. Most of Etna lies west of Mountain Rd. just north of its intersection with the
14 River Highway. Etna is built around four streets that surround the Town Park. On the eastern edge of the park, there is a white
15 Gazebo. The Gazebo is used to house the town band during afternoon concerts. Along the eastern edge of the Town Park runs
16 Mountain Rd. The other three streets in Etna are each only a block long. Along the southern border of the park runs Maple St. Maple
17 St. is lined with large maple trees. These maples, when they come alive with color in the fall are an attraction for many tourists.
18 Across the street from the park, on separate sides, lie three of the town's main buildings--the Town Hall, the Store, and the School.
19 Across the street from the east side of the park is the Town Hall. The Town Hall is the oldest structure in the town and one of the
20 buildings around which the town was built. Across the street from the north side of the park is the Store. People often gather at the
21 Store to find out the latest town news. Across the street from the west side of the park is the School. The little red, one-roomed
22 schoolhouse is the original school built when the town was founded. At the northwest corner of River Highway and Mountain Rd. is
23 the Gas Station. One of the mechanics from the Gas Station sits in front of the station office and waves to all the cars that drive
24 past.

25 **Town: Route Perspective**

26 One of the largest town fairs and pumpkin festivals in the United States is held each year in the town of Etna. Etna is a typical small
27 New England town with dirt roads and gravel sidewalks. The lay-out of the town has not changed much since it was founded in the
28 1700's. To reach Etna, drive east along the River Highway to where the highway crosses the White River. Continuing on the River
29 Highway past the river, you come to, on your left, Mountain Rd. You have reached the town of Etna. As you turn left onto Mountain
30 Rd. from the River Highway, you see, on your immediate left, the Gas Station. One of the mechanics from the Gas Station sits in
31 front of the station office and waves to all the cars that drive past. Straight ahead, you can see the road disappearing into the distant
32 White Mountains. You drive on Mountain Rd. a block past the Gas Station, and come to, on your left, Maple St. Turning left onto
33 Maple St., you see that the street is lined with large maple trees. These maples, when they come alive with color in the fall, are an
34 attraction for many tourists. After turning left onto Maple St. from Mountain Rd., you see, on your right, the Town Park--a central
35 feature of Etna. You travel a block on Maple St. and are forced to make a right turn. On your left, about a half a block after you turn
36 off of Maple St., is the School. The little red, one-roomed schoolhouse is the original school built when the town was founded.
37 Continuing along this street for another half a block, you are again forced to make a right turn. You turn and drive a half a block
38 where you see, on your left, the Store. People often gather at the Store to find out the latest town news. This road continues for
39 another half a block where it dead-ends into Mountain Rd. After you make a right turn onto Mountain Rd., you drive about a half a
40 block to where you see, on your left, the Town Hall. The Town Hall is the oldest structure in the town and one of the buildings
41 around which the town was built. From your position with the Town Hall on your left, you see, on your right, a white Gazebo near the
42 edge of the park. The Gazebo is used to house the town band during afternoon concerts. You return to where Mountain Rd dead-
43 ends into the River Highway. You turn left from Mountain Rd. and leave the town of Etna by taking the River Highway.
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Appendix B. Statement verification task stimuli for the convention center, zoo, resort, and town environments.

Convention Center

Verbatim Locative (route)

1. As you walk into the building, you see, on your left, a Bulletin Board.
2. You walk past the Televisions, on your right, and continue forward until you see, again on your right, the VCR's.
3. Walking past the Movie Cameras on your right, you see, again on your right, the 35mm Cameras.
4. Continuing straight ahead from the entrance, where the Bulletin Board is on your left, you reach, on your right, the Movie Cameras.

Verbatim Locative (survey)

1. Along the north wall, directly west of the Personal Computers are the Stereo Components.
2. Directly south of the Cafeteria, on the west wall, are the Restrooms.
3. In the northwest corner of the center section, with the entrance facing north, are the Televisions.
4. East of the Bulletin Board, on the east side of the building near the southeast corner, is the entrance.

Verbatim Non-locative

1. Several companies that manufacture electronics have decided to get together for a convention to show their wares.
2. The Cafeteria is privately run by a family that leases the space on a permanent basis from the Convention Center.
3. Like many Television Displays, the sets are lined up along the walls, all tuned to the same station.
4. Temporary wall dividers are used to separate the displays and to form a single entrance to each display.

Inference (route)

1. Looking into the Movie Camera Display, the Bulletin Board is behind you.
2. Walking from the Personal Computers to the Televisions, you pass, on your right, the Stereo Components.
3. Looking into the VCR display, the Cafeteria is to your right.
4. Walking from the Stereo Components to the CD's, you pass, on your right, the 35mm Cameras.
5. Walking from the Restrooms to the entrance, you pass, on your right, the CD Players.
6. Looking into the Cafeteria, the Office is to your left.

Inference (survey)

1. The VCR's are north of the Movie Cameras and east of the Televisions.
2. Directly east of the Cafeteria are the CD Players.
3. The Cafeteria is northwest of the entrance and north of the Restrooms.
4. South of the 35mm Cameras are the Televisions.
5. Directly south of the Office are the Restrooms.
6. The Personal Computers are west of the Cafeteria and south of the entrance.

Zoo

Verbatim Locative (route)

1. The entrance leads you directly into the Children's Zoo.
2. As you enter the Large Mammals section from the Arctic Animals section, you find yourself in front of two cages.
3. As soon as you enter the Zoo, you see, on your right, the ticket booth.
4. You walk forward, passing the giraffes on your left, until you reach the Facilities, located to your right and in the center of the Zoo.

Verbatim Locative (survey)

1. On the west side of the Children's Zoo is the Duck Pond.
2. There are two cages within the Arctic Animal section--the Penguins' and the Polar Bears'.
3. On the west side of the Large Mammals section are the elephants.
4. In the southeast section of the Zoo are the Primates.

Verbatim Non-locative

1. The giraffes like to try to stretch their necks even further to eat the leaves on the trees.
2. The specialty of the snack bar is a drink called Orange Whip, which is made by mixing orange sherbet and orange juice.
3. In springtime, when the new ducklings hatch, is the best time to see the duck pond.
4. Within the Facilities complex is an information window, a gift shop, and a snack bar.

Inference (route)

1. Standing at the Penguins' Building facing the Large Mammals, the Chimp Show is to your right.
2. Looking toward the Children's Zoo from the center of the facilities, the Arctic Animals section is behind you.
3. Walking from the Children's Zoo to the Large Mammals section, the first cage you come to is the giraffes.
4. Walking from the Large Mammals section to the Arctic Animals section, the first cage you come to is the Polar Bears'.
5. Walking from the entrance, you will have to turn left to get to the Large Mammal section.
6. Looking toward the Arctic Animals section from between the two cages in the Primate section, the Baboon Colony is to your right.

Inference (survey)

1. The ticket booth is north of the Lamb Petting Area.
2. The Elephants' Cage is northwest of the Baboon Colony.
3. The Duck Pond is north of the Chimp Show and east of the Giraffe Cage.
4. The Penguin Building is east of the Chimp Show.
5. The Giraffes' Cage is west of the Polar Bears' Cage and south of the Baboon Colony.
6. The Duck Pond is northwest of the Penguin Building and east of the Chimp Show.

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Resort

Verbatim Locative (route)

1. You turn left onto the Forest Highway and go along until you reach, on your right, Horseshoe Drive.
2. After going along Horseshoe drive for some time, you see, on your left, the small town of Madison.
3. From your position with Lincoln on your right, you see, on your left, the Fishing Pier and Boat Launch for Pigeon Lake.
4. From your position with the Swimming Beach on your left, you see, on your right, the town of Jefferson.

Verbatim Locative (survey)

1. Running north-south along the western border of this region is Bay Rd.
2. The northern border for the region and the link between Bay Rd. and the National Forest is made up of the Forest Highway.
3. On the east side of the lake, on the National Forest side of Horseshoe Dr. is the town of Jefferson.
4. On the west side of the lake, between the lake and Horseshoe Dr. is the town of Madison.

Verbatim Non-locative

1. Madison is the site of the Annual Seafood Festival where the main event is the fishing contest.
2. Since there is only one boat launch for Pigeon Lake, there is usually quite a bit of traffic near the launch site.
3. Jefferson is the main center for hiking and cycling in the area.
4. The National Forest has facilities for camping, hiking, and rock climbing.

Inference (route)

1. From your position with the town of Jefferson to your right, Matilda Bay is behind you.
2. Walking toward the town of Lincoln with the pier and boat launch on your left, the National Forest is straight ahead.
3. Walking from Bay Rd. to the National Forest, you pass Pigeon Lake on your right.
4. From your position with the town of Madison to your right, Pigeon Lake is to your left.
5. Walking toward Matilda Bay with the town of Madison on your left, Bay Rd. is behind you.
6. Coming from the town of Jefferson to the town of Lincoln, you will see the National Forest on your right.

Inference (survey)

1. The closest town to the pier and boat launch is Lincoln.
2. The town of Madison is west of the town of Jefferson and north of Lincoln.
3. Directly across Horseshoe Drive from the town of Lincoln is the pier.
4. The National Forest is west of Bay Rd.
5. On the north side of Forest Highway is the town of Madison.
6. Directly across Pigeon Lake from the pier is the town of Lincoln.

Town

Verbatim Locative (route)

1. As you turn left onto Mountain Rd. from River Highway, you see, on your immediate left, the Gas Station.
2. You drive on Mountain Rd. a block past the Gas Station, and come to, on your left, Maple St.
3. After turning left onto Maple St. from Mountain Rd., you see, on your right, the Town Park--a central feature of Etna.
4. From your position with the Town Hall on your left, you see, on your right, a white Gazebo near the edge of the park.

Verbatim Locative (survey)

1. The northern border is made up of the White Mountain Range.
2. Along the eastern edge of the Town Park runs Mountain Rd.
3. On the eastern edge of the Town Park, there is a white Gazebo .
4. At the northwest corner of River Highway and Mountain Rd. is the Gas Station.

Verbatim Non-locative

1. Etna is a typical small New England town.
2. The Town Hall is the oldest structure in the town and one of the buildings around which the town was built.
3. One of the largest town fairs and pumpkin festivals in the United States is held each year in the town of Etna.
4. People often gather at the Store to find out the latest town news.

Inference (route)

1. From your position with the Town Hall on your left, the White Mountains are behind you.
2. Driving toward Mountain Rd. on Maple St., the School is behind you.
3. Driving from the Town Hall to the Gas Station, you pass Maple St on your right.
4. Driving toward the White Mountains on Mountain Rd., the Gas Station and the Town Hall will both be on your right.
5. Coming from the White Mountains on Mountain Rd., you turn left to reach the Store.
6. Driving toward Mountain Rd. from the Store, you see, on your left, the Gazebo.

Inference (survey)

1. The closest building to the White River is the School.
2. The Gas Station is east of the river and south of Maple St.
3. Directly across the Mountain Rd. from the Gazebo is the Town Hall.
4. The School is on a road that runs east-west.
5. On the west side of Mountain Rd. is the Town Hall.
6. Directly across the park from the School is the Gas Station.