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Recollection and Unitization in Associating Actors With Extrinsic and Intrinsic Motions

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Four experiments provide evidence for a distinction between 2 different kinds of motion representations. Extrinsic motions involve the path of an object with respect to an external frame of reference. Intrinsic motions involve the relative motions of the parts of an object. This research suggests that intrinsic motions are represented conjointly with information about the identities of the actors who perform them, whereas extrinsic motions are represented separately from identity information. Experiment 1 demonstrated that participants remembered which actor had performed a particular intrinsic motion better than they remembered which actor had performed a particular extrinsic motion. Experiment 2 replicated this effect with incidental encoding of actor information, suggesting that encoding intrinsic motions leads one to automatically encode identity information. The results of Experiments 3 and 4 were fit by Yonelinas's (1999) source-memory model to quantify the contributions of familiarity and recollection to memory for the actors who carried out the intrinsic and extrinsic motions. Successful performance with extrinsic motion items in Experiment 3 required participants to remember in which scene contexts an actor had appeared, whereas successful performance in Experiment 4 required participants to remember the exact path taken by an actor in each scene. In both experiments, discrimination of old and new combinations of actors and extrinsic motions relied strongly on recollection, suggesting independent but associated representations of actors and extrinsic motions. In contrast, participants discriminated old and new combinations of actors and intrinsic motions primarily on the basis of familiarity, suggesting unitized representations of actors and intrinsic motions.

Keywords: motion event, manner of motion, binding, hippocampus, superior temporal sulcus

On April 26th, 2009, a woman had just met her ex-husband in the parking lot of a metropolitan Atlanta shopping center to pick up their 19-month-old son as part of a custody agreement. After the woman strapped her son into his car seat, a stranger with dark hair and a mustache approached her car, briefly exchanged words with the woman, and then shot her in the head, killing her. The stranger then quickly walked away. A friend of the victim who later saw surveillance video of the attack recognized the assailant not as a man but rather as the victim's mother-in-law, based on her distinctive walk, which the friend described as "stiff legged" and having a "very wide stride." When the mother-in-law was later arrested and shown on TV, an eyewitness to the crime saw the footage and came forward saying that she recognized her on the basis of her "manner of walking." Two people thus identified the perpetrator of the murder by her walk. The mother-in-law was eventually convicted of the murder and sentenced to life imprisonment (*Hayes v. State*, 2013).

This case provides a dramatic example of how a person can become associated with particular actions, such that one can later identify that person solely on the basis of those actions. Perhaps most notably, the eyewitness to the murder, who had only observed the assailant on that one occasion, later recognized her on the basis of the way she walked. The eyewitness thus must have associated the assailant with a particular manner of walking, such that when she later saw a person on TV walking in that same manner this caused her to bring to mind her prior experience with the assailant.

Not all actions may be so readily associated with particular individuals, however. Kersten, Earles, Curtayne, and Lane (2008; see also Earles, Kersten, Curtayne, & Perle, 2008; Earles, Kersten, Vernon, & Starkings, in press) demonstrated that eyewitnesses often have great difficulty remembering which actions were associated with which people, even after seeing the same person perform the same action on multiple occasions (Kersten & Earles, 2010; Kersten, Earles, & Upshaw, 2013). An explanation is thus needed for the apparent disconnect between the results of this line of research and findings from criminal cases such as the one described above, in which an eyewitness associates an assailant with particular actions after seeing the assailant perform those actions on only a single occasion. The present research was designed to test whether certain types of actions are especially likely to be linked with particular individuals,

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making it easier for eyewitnesses to remember which people performed these actions.

Two Different Kinds of Motion

In an earlier line of research, Kersten (1998a, 1998b, 2003; Kersten, Smith, & Yoshida, 2006) proposed a division of labor between two different kinds of motion representations in the representation of a motion event. Extrinsic motions involve the path taken by an object or creature with respect to an external frame of reference, such as another object or creature. For example, in the case described above, the extrinsic motions of the assailant involved approaching the victim's car and later fleeing the scene. It is important to note that according to the division of labor theory, extrinsic motions can be adequately represented with the objects in motion instantiated simply by points or undifferentiated blobs. Extrinsic motion representations may thus include little or no information about the identities of the objects or creatures carrying out those motions.

In contrast to extrinsic motions, intrinsic motions involve the motions of the parts of an object with respect to the object as a whole. For example, in the case described above, the intrinsic motions of the assailant involved the particular way she moved her limbs in relation to her body to achieve locomotion (e.g., stiff legged with a wide stride). According to the division of labor theory, representations of intrinsic motions, unlike extrinsic motions, must make reference to the internal structure of an object, such as the sizes and points of attachment of the various limbs of a creature, so that one can represent how those parts move in relation to one another. In fact, Kersten (1998a) proposed that although representing extrinsic motions is a prototypical function of the *dorsal* (i.e., the "where") pathway in the brain (see Ungerleider & Mishkin, 1982), representing intrinsic motions may tap into the functioning of the *ventral* (i.e., the "what") pathway. The relative motions of the parts of an object may thus be conjointly represented with information about the appearances and configuration of those parts, providing information about the identities of the objects carrying out those motions.

Kersten (1998a) used a miniature artificial language learning task to provide support for the theory of a stronger relationship of identity information with intrinsic motions than with extrinsic motions. Participants in this task viewed a number of animated events, each involving two bug-like creatures moving around and interacting on a computer screen. Each such event was accompanied by a sentence involving a novel noun and verb (e.g., "The zeebee is spogging."). A particular noun or verb was always accompanied by both a particular intrinsic motion (i.e., a particular way in which the bug moved its legs in relation to its body) and a particular extrinsic motion (i.e., a particular path taken by one of the creatures in the event in relation to the other creature). Thus, participants could potentially have associated a noun or verb with an intrinsic motion, an extrinsic motion, or both. Nouns could also be distinguished on the basis of the static characteristics of the objects, however, and thus there was no requirement for participants to associate nouns with either type of motion to tell the nouns apart.

Participants were later tested on the types of information that they associated with each word by presenting them with pairs of events that differed on only one type of information and asking them which of the two events was the better example of a particular word. Participants were found to readily associate nouns not only with the static characteristics of the objects but also with intrinsic motions. This result provides evidence for a tight coupling between intrinsic motion and information about the identities of the objects carrying out those motions, as predicted by the division of labor theory. Participants performed significantly worse at selecting the extrinsic motion associated with a particular noun, consistent with a weaker link of extrinsic motions with static object information. Performance with verbs allowed one to rule out a simple salience explanation for the above findings, with participants performing better at selecting the extrinsic motion than at selecting the intrinsic motion associated with a verb. These results suggest that the extrinsic motions in the events were actually more salient to participants than were the intrinsic motions, but participants more readily associated nouns with intrinsic motions than with extrinsic motions, consistent with the division of labor theory.

The results of Kersten (1998a) provide evidence for an integral relationship between intrinsic motion and identity information. Other evidence for this relationship comes from research on point-light walkers. In this research, introduced by Johansson (1973), the various joints on the human body are replaced by points of light, which can then be used to show observers the motions of those joints while the actor is in locomotion, without any accompanying information about the appearance of the actor or the context in which the motions take place. Research with point-light walkers has revealed that observers can identify not only that the points of light represent a human figure but also the sex of the walker, the age of the walker, and sometimes even the identity of the walker (Cutting & Kozlowski, 1977; Kozlowski & Cutting, 1977; Loula, Prasad, Harber, & Shiffrar, 2005; Montepare & Zebrowitz-McArthur, 1988). The information present in the point-light images that allows people to identify the walkers would appear to principally involve intrinsic motions, displaying the relative motions of the parts of the human body in the absence of external reference points. The finding that observers can identify familiar individuals solely on the basis of these motions is consistent with the proposal from the division of labor theory that representations of objects (in this case, humans) may include information about how the parts of those objects typically move in relation to one another.

The division of labor theory may offer an explanation for why eyewitnesses so readily associate certain types of motion with particular individuals, whereas other types of motion are more difficult to associate with a particular person. In particular, on encountering an assailant, an eyewitness may form a memory representation for the assailant, including not only information about the appearances of the various body parts of the assailant but also the particular manner in which those parts move in relation to one another during locomotion (e.g., stiff legged, with a very wide stride). Thus, when later presented with that same movement information, the eyewitness may be able to identify the person moving in that way as the assailant. Eyewitnesses may have greater difficulty associating an assailant with particular extrinsic motions, such as the particular path he or she followed (e.g., to the car, away from the crime scene), because these motions would be represented independently of information about the identity of the assailant. Thus, detailed knowledge of the path taken by the assailant while carrying

out the crime still may not help an eyewitness remember any identifying information about the assailant.

If extrinsic motion information is represented independently of identity information, how can eyewitnesses remember which person they saw taking a particular path (e.g., leaving a crime scene)? Putting these two pieces of information together may require not only the formation of separate memory representations for the two pieces of information but also an associative or binding process relating them, indicating that they belonged together at least at one point in time. In contrast, intrinsic motion information may be directly represented along with identity information as part of a unitary memory representation.

Recollection and Unitization

The notion of representing identity and action information in independent but associated representations, as opposed to directly including action information as an integral part of a person representation, may be related to a distinction in the source-memory literature between recollection and unitization (Diana, Yonelinas, & Ranganath, 2008). *Recollection* involves retrieval of contextual information associated with the presentation of target information, possibly allowing one to infer the source of that information. For example, if one remembers sitting in a lecture hall when a particular piece of information was presented, bringing to mind visual details that were present at the time such as the general layout of the room and fellow students who were sitting nearby, one may infer that one's professor was the source of that information. *Unitization*, on the other hand, involves conjointly representing target and source information as part of the same memory representation. For example, if one remembers hearing a particular piece of information spoken in the deep, booming voice of a particular news anchor, then one may conclude that the news anchor was the source of that information.

Memory for which person performed a particular action can be considered to be a source-memory task, with the particular motions that were seen performed serving as target information and the identity of the actor who performed those motions as source information. For example, in the case described above, if one considers the actions of approaching the victim's car and shooting the victim as the target information to be remembered, then the perpetrator of these actions can be considered to be the source of that information.

Diana et al. (2008) have proposed that memory for the source of target information typically involves recollection of independently represented contextual details associated with that information. For example, on retrieval of information about the actions of an assailant, an eyewitness may use this information to retrieve associated details about the context in which that information was encountered, such as the parking lot in which the event took place, what time of day it was, what the car and the gun looked like, and (possibly) details about the appearance of the assailant who carried out those actions. Critically, this retrieval of contextual details is thought to depend on the binding of independent representations of target information and contextual information. If this retrieval is successful, it may bring about a phenomenological experience of recollection or a reexperiencing of the retrieved aspects of the event, causing one to be highly confident in the retrieved information. If retrieval is unsuccessful, no such recollective experience occurs, and one must rely instead on vague feelings of familiarity for any information that is brought to mind, leading to more graded levels of confidence in one's memory for the event.

In contrast to the recollection of independently represented contextual details that are only associated with target information, Diana et al. (2008) argued that source-specifying information is sometimes represented together with target information in unitized memory representations. This unitization is thought to occur when target information is encoded in such a way that it provides clues to the source of that information. For example, if an eyewitness to the crime described above had been able to overhear the words that the assailant had said to the victim before shooting her and encoded those words in the sound of the assailant's voice, this representation would provide evidence regarding the source of those words (e.g., that the source was female).

At the heart of the distinction between unitization and recollection is that when target and source information are unitized, one may distinguish between the correct and incorrect sources of information on the basis of familiarity. In particular, because target information is conjointly represented with features of the source of that information, when that same target information is presented by a different source, it will fail to register as familiar because of the mismatch on source features. For example, if an eyewitness who overheard the words spoken by the assailant was later presented with a police lineup in which lineup members were asked to repeat those words (as is sometimes done in actual lineups; see, e.g., Doyle, 2005), those words spoken by the true assailant would be expected to lead to a feeling of familiarity, possibly leading one to identify that person as the assailant. Those same words spoken by a different person, on the other hand, would fail to fully match the unitized representation of the word–voice combination, leading to weaker feelings of familiarity and thus a reduced likelihood of selecting that lineup member.

In contrast to unitized representations of target and source information, when target and source information are represented separately, then that same target information presented by another source will still match the target representation, yielding a feeling of familiarity for the information. If this other source is also familiar, having previously been encountered in other contexts, then the combination of familiar target information and familiar source information will cause one to experience a strong feeling of familiarity. The only way of distinguishing this novel combination of familiar target and source information from that same target information presented by its original source may thus be to retrieve an association between the target information and independently represented information about the original source of that information. This recollection of the original target–source pairing would encourage one to accept a repairing of these same two pieces of information, whereas it would allow one to reject a novel combination of familiar target and source information despite the global feeling of familiarity that it engenders.

In support of their theory, Diana et al. (2008) revealed that source-memory performance (i.e., memory for the background color on which a word had appeared) was significantly better following encoding instructions that encouraged unitization of target and source information (i.e., imagining the referent of a word painted in the background color on which the word appeared) than in the condition that encouraged independent representations of target and source information (i.e., performing one of two

different judgments on the word depending on the background color). Moreover, this advantage of the unitized condition was most evident for source-memory judgments made with intermediate levels of confidence, suggesting that participants in the unitized condition were relying on continuously varying levels of familiarity of target–source combinations when deciding whether a word had appeared with a particular background color. When analysis was limited to source-memory judgments made with the highest level of confidence, performance was equally good in the two conditions. This finding suggests that participants in the nonunitized condition were just as good as participants in the unitized condition at using target information to retrieve independent but associated representations of source information, leading to a phenomenological experience of recollection and thus high-confidence recognition judgments.

The theory of Kersten (1998a, 1998b, 2003) suggests that intrinsic motion information may be represented together with source information in unitized memory representations, including information both about the motions themselves and about the particular body parts that carry out those motions. Thus, it should be possible for participants to distinguish between the correct and incorrect source of a particular intrinsic motion on the basis of familiarity. In particular, a familiar intrinsic motion performed by the wrong actor should not engender a feeling of familiarity because of the mismatch in actor features, whereas that same motion performed by the correct actor will be perceived as familiar. In contrast, extrinsic motion information may be represented separately from source information, requiring retrieval of an external association between that extrinsic motion representation and the representation of the identity of the original actor who had performed that motion to distinguish between the correct and incorrect source of a particular extrinsic motion. Thus, observers should perform better at remembering the source of an intrinsic motion (i.e., the person who performed that motion) than at remembering the source of an extrinsic motion. Moreover, this intrinsic motion advantage should be most evident at intermediate levels of confidence, reflecting the use of the familiarity of a person–intrinsic motion combination to distinguish it from novel combinations of people and intrinsic motions. The present experiments tested these predictions.

Associating Actors With Actions

The present experiments used a methodology similar to that of Kersten et al. (2008) to test the ability of participants to remember which actor performed each of a number of actions. Participants were presented with a series of events (see Figure 1), each involving one of 10 different actors exhibiting a particular intrinsic motion (e.g., walking, doing somersaults, doing cartwheels) while moving along a particular path (i.e., an extrinsic motion) with respect to an environmental landmark (e.g., down a hill, around a sign, out of a building). One week

Figure 1. Still frames from example encoding items. The actual encoding stimuli involved full-motion videos presented in color on 17-in. computer monitors. The four frames depicted here represent shuffling feet up the ramp in a parking deck (upper left), marching to water pipes (upper right), doing a running long jump to a volleyball net (lower left), and doing butt-kicks around a street sign (lower right). The individuals whose images appear in this figure have signed consent for their likenesses to be published in this article. See the online article for the color version of this figure.

later, participants were tested on their recognition memory for these events. Some of the recognition items, the extrinsic conjunction items, involved an actor moving with the same intrinsic motion as before but now following a path that had been followed by a different actor (see Figure 2). Discriminating these extrinsic conjunction items from old items was expected to require participants to recollect which actor had followed each path earlier, encouraging them to accept an item involving an actor performing the same path as before but to reject an item involving a path performed by the wrong actor.

Other recognition items, the intrinsic conjunction items, involved an actor following the same path as before but performing an intrinsic motion that had previously been performed by a different actor. Participants were expected to be able to discriminate these intrinsic conjunction items from old items on the basis of familiarity. In particular, a familiar intrinsic motion performed by the wrong actor was not expected to elicit a strong feeling of familiarity because it would fail to fully match a previously established unitized representation of an actor–intrinsic motion combination. The same intrinsic motion performed by the same actor as

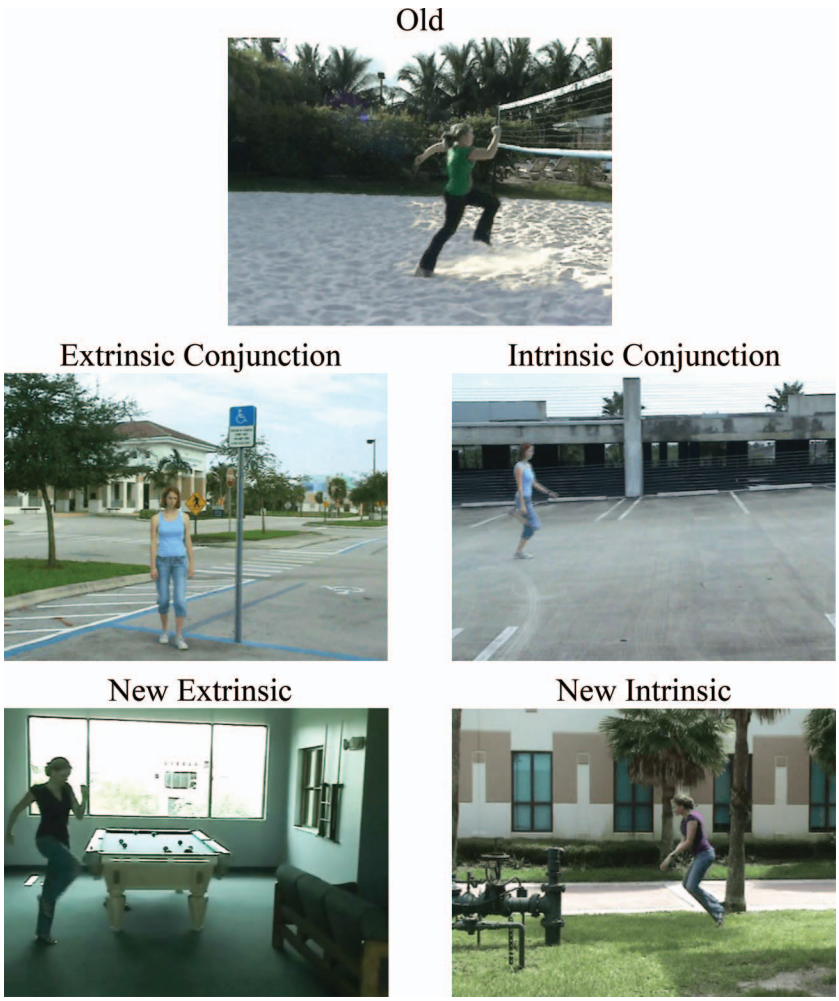

Figure 2. Still frames from example retrieval items. Old items were identical to stimuli seen at encoding. Extrinsic conjunction items involved an actor exhibiting the same intrinsic motions she had performed earlier but following a path previously taken by another person. For example, the actor appearing in the example extrinsic conjunction item was previously seen shuffling her feet, but it was a different actor who was seen moving around a street sign (see Figure 1). Intrinsic conjunction items involved an actor following the same path she had taken earlier, but exhibiting intrinsic motions that had previously been performed by a different actor. For example, the actor appearing in the example intrinsic conjunction item was previously seen going up the ramp in a parking deck, but it was a different actor who was seen doing butt-kicks (see Figure 1). New extrinsic items involved an actor exhibiting the same intrinsic motions she had performed earlier, but following a path not seen at encoding (e.g., around the pool table). New intrinsic items involved an actor following the same path she had taken earlier, but exhibiting intrinsic motions not seen at encoding (e.g., leapfrogging). The individuals whose images appear in this figure have signed consent for their likenesses to be published in this article. See the online article for the color version of this figure.

at encoding was expected to yield a stronger feeling of familiarity. Because familiarity could be used to distinguish old from intrinsic conjunction items but not to distinguish old from extrinsic conjunction items participants were predicted to perform better on the former discrimination.

In Experiment 1, we tested this prediction that participants should show better discrimination of old and intrinsic conjunction items than of old and extrinsic conjunction items in the context of an instruction set that encouraged participants to attend to both types of motion information, as well as the identities of the actors who performed them (thus likely also encouraging attention to facial and bodily structure). In Experiment 2, we tested whether this same effect would be observed when participants were simply instructed to attend to one of these two types of motion, without any encouragement to remember which actor performed each motion. If intrinsic motions are represented in terms of the appearances and configurations of body parts that carry out those motions, then participants should encode the identities of the actors who carry out those motions even if they are not explicitly instructed to do so.

Finally, in Experiments 3 and 4 we used Yonelinas's (1999) dual-process model of source-memory performance to formally estimate influences of familiarity and recollection on the discrimination of old items from intrinsic and extrinsic conjunction items. Extrinsic conjunction items in Experiment 3 involved an actor following a path that had previously been followed by a different actor in relation to a background scene, and the actor in the extrinsic conjunction item had never previously appeared within that scene context. Participants could thus potentially use memory for which actors had appeared in which scenes to discriminate old and extrinsic conjunction items. Extrinsic conjunction items in Experiment 4 involved an actor appearing in a scene context in which she had appeared earlier but now following a path that had been taken by a different actor within that scene. Participants thus had to remember the exact path the actor had taken within that scene to discriminate old and extrinsic conjunction items. Intrinsic conjunction items in both experiments involved an actor performing an intrinsic motion that had previously been performed by a different actor. If extrinsic motions but not intrinsic motions are represented independently of identity information, then influences of recollection should be greater when discriminating old items from extrinsic conjunction items than when discriminating old items from intrinsic conjunction items. In contrast, if intrinsic motions but not extrinsic motions are represented together with identity information in unitized memory representations, then influences of familiarity should be greater when discriminating old items from intrinsic conjunction items than when discriminating old items from extrinsic conjunction items.

Experiment 1

Method

Participants. Forty-five undergraduates enrolled in general psychology classes received course credit for participation in this experiment.

Stimuli. The stimuli for this experiment consisted of 180 color video clips displayed on 17-in. color computer monitors without any accompanying audio. The duration of the video clips ranged from approximately 1 s to 23 s ($M = 6$ s). The actors in the video clips were 10 female undergraduates. Each video clip depicted a unique motion event, involving an actor performing a unique combination of an extrinsic and an intrinsic motion. The 50 different extrinsic motions each involved one of eight different general directions (to, away from, down, up, into, out of, past, around) with respect to a particular landmark (e.g., a statue, fountain, or building). The 50 different intrinsic motions each involved a particular way of moving one's body parts in relation to one another to achieve motion of the body as a whole (e.g., walking backward, hopping, doing somersaults). Appendix A lists the 50 different extrinsic and intrinsic motions.

There were five different encoding lists, each consisting of 40 videos involving 40 different extrinsic motions and 40 different intrinsic motions. Each of the 10 actors appeared in four of the videos in a given encoding list. There were also five different retrieval lists, each corresponding to one of the encoding lists. Each retrieval list consisted of 50 videos involving 50 different extrinsic motions and 50 different intrinsic motions. Each of the 10 actors appeared in five of the videos in a given retrieval list.

There were five different kinds of retrieval items. Ten old items were identical to items in the corresponding encoding list. Twenty conjunction items involved an actor performing a motion that was associated with a different actor in the corresponding encoding list. Of these, 10 extrinsic conjunction items involved an actor performing an intrinsic motion that was associated with that same actor at encoding, but the extrinsic motion she was performing was associated with a different actor at encoding. The other 10 conjunction items, the intrinsic conjunction items, involved an actor performing an extrinsic motion that was associated with that same actor at encoding, but the intrinsic motion she was performing was associated with a different actor at encoding. Twenty new items involved an actor performing a motion that was not present in the corresponding encoding list. Of these, 10 new extrinsic motion items involved an actor performing an intrinsic motion that was associated with the same actor at encoding, but the extrinsic motion she was performing did not appear in the corresponding encoding list. The other 10 new items, the new intrinsic motion items, involved an actor performing an extrinsic motion that was associated with that same actor at encoding, but the intrinsic motion she was performing did not appear in the corresponding encoding list. Retrieval lists were counterbalanced such that a given video appeared equally often as an old item, an extrinsic conjunction item, an intrinsic conjunction item, a new extrinsic motion item, and a new intrinsic motion item.

Procedure. After signing the consent form, each participant was led individually to a computer. Participants were instructed that they would view a number of video clips, each involving a person moving in a particular way to get somewhere. They were instructed to remember as much as possible about each of these video clips, including the person involved, where she was going, and the movements she used to get there. They were further instructed that at the end of each video clip, they would need to click on a button labeled "continue" to view the next video clip. Participants then viewed the 40 video clips in their assigned encoding list in a unique random order for each participant. After viewing the last video clip, participants completed a demographics questionnaire on the computer, after which they completed a test of their vocabulary knowledge (Shipley, 1986). They were then in-

vited to return one week later for the second session of the experiment.

In the second session, participants were instructed that they were to view a new set of video clips, some of which they had seen previously and some of which were new. They were instructed that after each video clip, they would be asked, "Did you see this video clip in the first part of the experiment?" They were instructed that if during the first part of the experiment they had seen a video clip involving the same person going to the same place using the same body movements, they should click on the "yes" button but that if any of these three aspects of the video clip had changed they should click on the "no" button. Finally, they were instructed that after selecting either the "yes" or "no" button, they would be asked to rate their confidence in their judgment on a three-point scale (1 = *just guessing*, 2 = *pretty sure*, 3 = *absolutely sure*).

Following the instructions, each participant viewed the 50 video clips in their assigned retrieval list, presented in a unique random order for each participant.

Design. The independent variable in this experiment was item type (old vs. extrinsic conjunction vs. intrinsic conjunction vs. new extrinsic motion vs. new intrinsic motion), manipulated within subjects. The primary dependent variable involved the proportions of "yes" responses to the different types of recognition items.

Results

The proportions of "yes" responses to the different item types are displayed in Figure 3. These results were analyzed using an analysis of variance (ANOVA) with item type as the independent variable, with the effects of item type analyzed in terms of a set of orthogonal planned comparisons. An alpha level of .05 was adopted for all analyses. The first comparison contrasted "yes" responses to old items with "yes" responses to the four types of recognition foils, providing a global measure of participants' abilities at discriminating old and new recognition items. This comparison revealed a significantly higher proportion of "yes" responses to old items than to recognition foils, $F(1, 44) = 309.04$, $MSE = 0.02$, $p < .001$, $\eta_p^2 = 0.88$, indicating that participants were successful at remembering at least some of the events they had seen one week earlier.

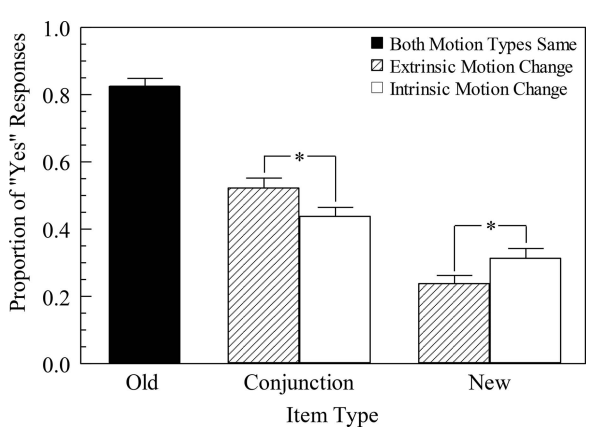

Figure 3. Proportions of "yes" responses to the different types of recognition items in Experiment 1. Error bars represent standard errors. * indicates $p < .05$ on the within subjects comparison between two item types.

The second comparison contrasted "yes" responses to conjunction items with "yes" responses to new items. This comparison measured influences of the familiarity of the motions appearing in a test event, with conjunction items involving two familiar motions and new items involving one familiar and one unfamiliar motion. This comparison revealed a significantly higher proportion of "yes" responses to conjunction items than to new items, $F(1, 44) = 78.51$, $MSE = 0.02$, $p < .001$, $\eta_p^2 = 0.64$, suggesting that the greater familiarity of the conjunction items caused participants to be more likely to believe that they had seen those events earlier.

The third comparison contrasted "yes" responses to extrinsic conjunction items with "yes" responses to intrinsic conjunction items. This comparison provided a test of the theory that intrinsic motion representations are more likely than extrinsic motion representations to include information about the identities of the actors carrying out those motions, thus making it easier to reject an event involving a familiar intrinsic motion performed by the wrong actor than to reject an event involving a familiar extrinsic motion performed by the wrong actor. This comparison revealed a significantly higher proportion of "yes" responses to extrinsic conjunction items than to intrinsic conjunction items, $F(1, 44) = 5.39$, $MSE = 0.03$, $p = .025$, $\eta_p^2 = 0.11$, providing support for the principal prediction of Experiment 1.

Finally, the fourth comparison contrasted "yes" responses to new extrinsic motion items with "yes" responses to new intrinsic motion items, providing a measure of the relative salience of the two types of motion in the video clips. This comparison revealed a significantly higher proportion of "yes" responses to new intrinsic motion items than to new extrinsic motion items, $F(1, 44) = 6.56$, $MSE = 0.02$, $p = .014$, $\eta_p^2 = 0.13$. This finding suggests that extrinsic motions were somewhat more salient than intrinsic motions. Thus, the higher rate of false recognition of the extrinsic conjunction items than of the intrinsic conjunction items (as revealed by the third comparison above) cannot be explained by a failure to notice extrinsic motions, but rather it appears to reflect a failure to associate those motions with the correct actors.

Discussion

The results of Experiment 1 are consistent with the theory that intrinsic motions are represented in terms of particular body parts moving in particular ways with respect to one another. Thus, when presented with an actor performing an intrinsic motion that had previously been performed by somebody else, this motion may not have appeared familiar to participants because of changes in the appearance of the body parts carrying out that motion. In contrast, extrinsic motions may be represented independently of the identities of the actors carrying out those motions. Thus, when presented with an actor performing an extrinsic motion that had previously been performed by somebody else, this motion may have been more likely to appear familiar to participants, causing them to believe that they had previously seen this same actor perform this same motion.

Experiment 1 thus provides an initial demonstration that, when instructed to remember which actor performed a particular combination of extrinsic and intrinsic motion, participants were more successful at remembering which actor performed the intrinsic motion than at remembering which actor performed the extrinsic motion. If representations of intrinsic motions naturally include

information about the identities of the actors carrying out those motions, however, as suggested by the division of labor theory of Kersten (1998a), then participants should readily associate intrinsic motions with particular actors regardless of whether or not they are instructed to do so. Experiment 2 was designed to test this prediction.

Experiment 2

In Experiment 2, rather than instructing participants to remember which actor performed each extrinsic and intrinsic motion, we simply instructed participants to remember all of the different examples of one of these two types of motion, without mention of trying to remember which actor performed each motion. To enforce these instructions, we asked participants to make a judgment after each encoding event that required attention to the relevant type of motion. One week later, when participants returned for the recognition memory test, they were informed that they would not only be tested on their memory for the type of motion to which they had been instructed to attend but also on their memory for the other type of motion, as well as their memory for which person had performed each of these different types of motion. They were then given the same memory test as was given in Experiment 1.

Method

Participants. One hundred undergraduates enrolled in general psychology classes received course credit for participation in this experiment.

Stimuli and procedure. The encoding stimuli were identical to those in Experiment 1. In contrast to Experiment 1 half of the participants in Experiment 2, the attend to extrinsic motion condition, were instructed to remember the direction taken by the actor in each video clip with respect to the most prominent landmark in the video clip, such as a building or a piece of furniture. After each video clip was completed, these participants were asked to select which of eight sentences best described the direction the actor had taken. In particular, eight buttons appeared in a column against a white background labeled with the following eight sentences: "She went into it," "She came out of it," "She went past it," "She went around it," "She went up it," "She went down it," "She went to it," and "She went away from it." After participants clicked on one of these eight buttons, the buttons disappeared and the next video was presented.

The other half of the participants, the attend to intrinsic motion condition, were instructed to remember the manner in which the actor in each video clip was moving. After each video clip was completed, these participants were asked to select which English verb best described the manner in which the actor had moved (for related methodologies, see Billman & Krych, 1998; Billman, Swilley, & Krych, 2000; Gennari, Sloman, Malt, & Fitch, 2002). Eight buttons were labeled by the following eight sentences: "She crawled," "She danced," "She hopped," "She jumped," "She ran," "She rolled," "She walked," and "She did something that couldn't be described by any of these verbs." Again, after participants clicked on one of these eight buttons, the buttons disappeared, and the next video was presented.

When participants returned for the second session one week later, they were instructed that although they had been asked to remember a particular type of motion (of which they were reminded), they would also be tested on their memory for the other type of motion (examples of which were now described), as well as their memory for which person had performed each of these motions. They were instructed that they would see a number of video clips, each accompanied by the question "Did you see this video clip in the first part of the experiment?" and that if any of the three types of information (i.e., the actor, the direction she was going, and the manner in which she was moving) had changed from the original video that they should respond "no." They were then presented with the same test stimuli as in Experiment 1.

Design. The independent variables in this experiment were item type (old vs. extrinsic conjunction vs. intrinsic conjunction vs. new extrinsic motion vs. new intrinsic motion), manipulated within subjects, and encoding condition (attend to extrinsic motion vs. attend to intrinsic motion) manipulated between subjects. The primary dependent variable involved the proportions of "yes" responses to the different types of recognition items.

Results

The proportions of "yes" responses to the different item types are displayed in Figure 4. These results were analyzed using an

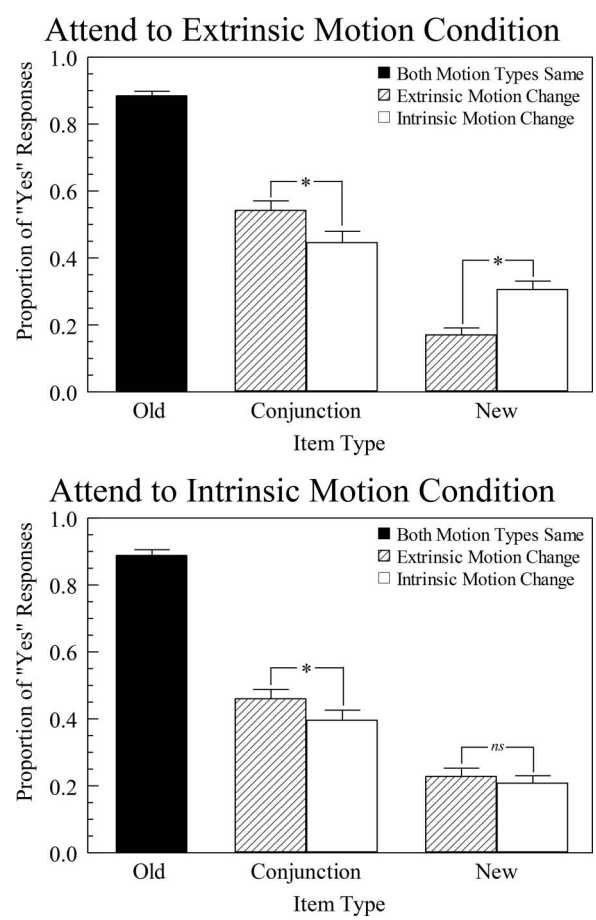

Figure 4. Proportions of "yes" responses to the different types of recognition items in Experiment 2. Error bars represent standard errors. * indicates $p < .05$ on the within subjects comparison between two item types, whereas *ns* indicates $p > .10$.

ANOVA with encoding condition and item type as independent variables. There was not a significant main effect of encoding condition, $F(1, 98) = 1.99$, $MSE = 0.07$, $p > .10$, $\eta_p^2 = 0.02$, indicating that there was not a significant difference between the two encoding conditions in their overall likelihood of responding "yes" to the recognition items.

The effects of item type were analyzed in terms of the same set of orthogonal planned comparisons that were used in Experiment 1. The first comparison revealed a significantly higher proportion of "yes" responses to old items than to recognition foils, $F(1, 98) = 1412.91$, $MSE = 0.02$, $p < .001$, $\eta_p^2 = 0.94$. This comparison did not interact with encoding condition, $F(1, 98) = 2.66$, $MSE = 0.02$, $p > .10$, $\eta_p^2 = 0.03$, indicating that the two conditions performed comparably in terms of overall old–new discrimination performance.

The second comparison revealed a significantly higher proportion of "yes" responses to conjunction items than to new items, $F(1, 98) = 236.12$, $MSE = 0.02$, $p < .001$, $\eta_p^2 = 0.71$. This comparison did not interact with encoding condition, $F(1, 98) = 2.30$, $MSE = 0.02$, $p > .10$, $\eta_p^2 = 0.02$, indicating that both conditions were influenced by the familiarity of the conjunction items, causing them to be more likely to believe that they had seen those items before than to believe that they had seen the new items before.

The third comparison revealed a higher rate of false recognition of extrinsic conjunction items than of intrinsic conjunction items, $F(1, 98) = 11.13$, $MSE = 0.03$, $p = .001$, $\eta_p^2 = 0.10$, replicating the principal result of Experiment 1. This comparison did not interact with encoding condition, $F(1, 98) = 0.45$, $MSE = 0.03$, $p > .10$, $\eta_p^2 = 0.00$, with a higher rate of false recognition of extrinsic conjunction items than of intrinsic conjunction items both in the attend to extrinsic motion condition, $t(49) = 2.55$, $p = .01$, and in the attend to intrinsic motion condition, $t(49) = 2.16$, $p = .04$. Thus, regardless of whether participants were instructed to remember extrinsic motions or intrinsic motions, they performed better at remembering which actor had performed a particular intrinsic motion than at remembering which actor had performed a particular extrinsic motion.

Finally, the fourth comparison revealed a significantly higher overall proportion of "yes" responses to new intrinsic motion items than to new extrinsic motion items, $F(1, 98) = 9.60$, $MSE = 0.02$, $p = .003$, $\eta_p^2 = 0.09$. This comparison interacted with encoding condition, $F(1, 98) = 17.36$, $MSE = 0.02$, $p < .001$, $\eta_p^2 = 0.15$, indicating that the relative salience of the two types of motion varied with encoding instructions. In particular, when participants were instructed to attend to extrinsic motions, they were significantly less likely to falsely recognize a new extrinsic motion than to falsely recognize a new intrinsic motion, $t(49) = 4.89$, $p < .001$. In contrast, when participants were instructed to attend to intrinsic motions, there was not a significant difference between their rates of false recognition of the new extrinsic motion and new intrinsic motion items, $t(49) = 0.80$, $p > .10$.

The results of this fourth comparison thus again suggest that the higher rate of false recognition of the extrinsic conjunction items than of the intrinsic conjunction items cannot be accounted for in terms of differences in salience of the two different kinds of motion. Participants who were instructed to attend to intrinsic motions were equally likely to falsely recognize new extrinsic motions and new intrinsic motions, suggesting that the two types of motion were equally salient in this condition. Participants in this condition were still more likely to falsely recognize extrinsic conjunction items than to falsely recognize intrinsic conjunction items, however.

Moreover, when attention was directed instead to extrinsic motions, there was a trend toward reduced false recognition of new extrinsic motions compared with when attention was directed to intrinsic motions, $t(98) = 1.79$, $p = .08$, and yet the rate of false recognition of extrinsic conjunction items increased significantly compared to when attention was directed to intrinsic motions, $t(98) = 2.05$, $p = .04$. This suggests that, although orienting attention to extrinsic motions does indeed lead to increased memory for that type of motion (and thus increased feelings of familiarity for events involving familiar examples of extrinsic motions), it does not similarly result in increased memory for the actors responsible for those motions. In contrast, orienting attention to intrinsic motion resulted in significantly reduced false recognition of new intrinsic motions compared to when attention was directed to extrinsic motions, $t(98) = 2.94$, $p = .004$, but the trend was in the direction of decreased rather than increased false recognition of the intrinsic conjunction items, $t(98) = 1.11$, $p > .10$.

Discussion

Experiment 2 provides further support for the theory that intrinsic motion representations include information about the identities of the actors carrying out those motions, whereas extrinsic motions are represented separately from identity information. Participants were less likely to falsely recognize novel conjunctions of familiar actors and intrinsic motions than to falsely recognize novel conjunctions of familiar actors and extrinsic motions, even though they were never explicitly instructed to encode which actor had performed each motion. When participants were instructed to attend to extrinsic motions, their ability to discriminate old and new extrinsic motions improved, but their false recognition of extrinsic conjunction items also increased. This pattern of results suggests that attending to extrinsic motions led to increased memory for the motions themselves, but without a concomitant increase in memory for which actor performed those motions, consistent with the notion of independent representations of extrinsic motions and actor identities.

When participants were instructed to attend to intrinsic motions, their ability to discriminate old and new intrinsic motions also improved. This increased memory for intrinsic motions was not accompanied by increases in the rate of false recognition of the intrinsic conjunction items, however, with the trend in the direction of decreased false recognition of intrinsic conjunction items. This pattern of results suggests that attending to intrinsic motions led to increased memory not only for the motions themselves but also for the actors who had performed those motions, allowing them to reject an intrinsic motion performed by the wrong actor. These results are thus consistent with representations of intrinsic motion that include information about the identities of the actors who carry out those motions.

Although the results of Experiments 1 and 2 are consistent in showing lower rates of false recognition of intrinsic conjunction items than of extrinsic conjunction items, participants successfully rejected even the extrinsic conjunction items nearly half of the time. A possible explanation is that, although extrinsic motions

may be represented separately from information about the identities of the actors who carry out those motions, associations may often be formed between these separate representations. These associations would allow one to retrieve identity information given extrinsic motion information, and vice versa. This recollection of associated identity information may not be as reliable as directly including identity information as part of motion representations (as may be the case with intrinsic motions), but any success at retrieving such associations would allow one to distinguish between old items (for which the retrieved identity information would match the current actor) and conjunction items (for which the retrieved identity information would not match). Experiment 3 was designed to measure the influences of this recollection of associated identity information on memory for the actors that had been seen performing the different extrinsic and intrinsic motions.

Experiment 3

To estimate influences of recollection and familiarity on memory for the sources of extrinsic and intrinsic motions, we applied Yonelinas's (1999) dual-process source-memory model to a variant of the procedure used in Experiments 1 and 2. This model summarizes source-memory performance in terms of three parameters. R_t represents the probability of recollecting having previously been presented with the same information by the *same* source (i.e., the "target" source). R_l represents the probability of recollecting having previously been presented with the same information by a *different* source (i.e., the "lure" source). Finally, d' represents discrimination of information previously presented by the same source from information previously presented by a different source on the basis of the familiarity of the item–source combination.

If intrinsic motion representations are unitized with information about the sources of those motions (i.e., the actors who perform them), then it should be possible to discriminate old items from intrinsic conjunction items on the basis of familiarity, yielding a high d' parameter in the condition that is asked to make this discrimination. In contrast, if extrinsic motions are represented separately from information about the sources of those motions, then familiarity should be less diagnostic at discriminating old and extrinsic conjunction items, yielding a lower d' parameter in the condition that is asked to make this discrimination. Participants in this condition may instead have to rely on retrieval of associations between extrinsic motion representations and representations of the identities of the actors who had previously performed those motions. Recollection of having seen the actor in a target item perform the same extrinsic motion previously would be demonstrated by a high R_t parameter, whereas recollection of having previously seen a different actor perform the action now being performed in an extrinsic motion conjunction item would be demonstrated by a high R_l parameter.

Because Yonelinas's (1999) dual-process source-memory model was formulated to account for performance in a memory task in which there are only two categories of test items (i.e., target vs. lure), whereas Experiments 1 and 2 involved several types of recognition items (e.g., old vs. conjunction vs. new), each participant in Experiment 3 was only tested for discrimination of two types of test stimuli. For example, some participants were asked to distinguish between old items and extrinsic conjunction items, whereas others were asked to distinguish between old items and intrinsic conjunction items. Two additional conditions were asked to discriminate either old items from new extrinsic motions or old items from new intrinsic motions, providing baseline measures of memory for the two different types of motion independently of the identities of the actors who performed those motions.

Participants' yes/no recognition judgments to the different types of test items were combined with their ratings of confidence in those judgments, yielding a 6-point scale of confidence that a given item had been seen earlier (i.e., *absolutely sure yes, pretty sure yes, just guessing yes, just guessing no, pretty sure no, absolutely sure no*). Receiver operating characteristics (ROC) curves were then constructed by relating acceptance of target and lure items at different levels of confidence. These ROC curves were then fit by the model to estimate d', R_t, and R_l parameters for each condition. Details of the modeling procedure are provided in Appendix B.

Method

Participants. One hundred twenty-eight undergraduates enrolled in general psychology classes received course credit for participation in this experiment.

Stimuli and procedure. In Experiment 3, we used largely the same video stimuli that were used in Experiments 1 and 2. Participants who were assigned to the old–conjunction discrimination conditions viewed 44 video clips at encoding, involving 44 different intrinsic motions and 44 different extrinsic motions. The first three and the last three encoding items were identical for each participant and served as primacy and recency fillers. These items had not previously been used in Experiments 1 and 2 and involved six new actors performing six new intrinsic and extrinsic motions. Memory for these items was not tested at retrieval. Two additional filler items, also identical for each participant, were drawn from the stimuli that were used in Experiments 1 and 2 and were interspersed with the other encoding items. The remaining 36 encoding items were different for different conditions and were presented in a unique random order for each participant. Memory for these items was tested one week later using 24 test events, presented in a unique random order for each participant. For participants who were assigned the old–intrinsic conjunction discrimination, 12 of the test items were identical to items seen at encoding. The remaining 12 items involved an actor performing an extrinsic motion that was associated with that same actor at encoding, but the intrinsic motion she was performing was associated with a different actor at encoding. For participants who were assigned the old–extrinsic conjunction discrimination, 12 of the test items were again identical to items seen at encoding. The remaining 12 items involved an actor performing an intrinsic motion that was associated with the same actor at encoding, but the extrinsic motion she was performing was associated with a different actor at encoding. Two different encoding and retrieval lists were constructed for each discrimination condition, such that a given item served as an old item on one list and a conjunction item on the second list.

Two additional conditions were designed to examine a participant's ability to discriminate old and new examples of the two types of motion. These conditions thus measured the baseline memorability of the two individual types of motion, independently of one's ability to associate those two types of motion with the actors who performed them. For participants who were assigned the old–new intrinsic mo-

tion discrimination, 12 test items involved an actor performing the same intrinsic motion she had performed at encoding, whereas 12 test items involved intrinsic motions not seen at encoding. For participants who were assigned the old–new extrinsic motion discrimination, 12 test items involved an actor performing the same extrinsic motion she had performed at encoding, whereas 12 test items involved extrinsic motions not seen at encoding.

Pilot testing with the old–new discrimination conditions revealed that performance was near ceiling when old items were identical to items seen at encoding (i.e., old items matched encoding items on both intrinsic and extrinsic motion as well as the actor who had performed them). To make the difficulty of the old–new discrimination conditions more comparable to that of the old–conjunction discrimination conditions, the irrelevant type of motion (i.e., the type of motion to which participants were not instructed to attend) was always new in the old–new discrimination conditions. For example, if a participant in the old–new intrinsic motion discrimination condition had seen an actor marching to some water pipes at encoding, an old item might later involve that same actor marching around a pool table. In contrast, if that same participant saw an actor doing lunges past a flower statue at encoding, a new item might later involve that same actor jumping to a volleyball net. The irrelevant type of motion (in this case, extrinsic motion) was thus new in both the old and new items, whereas the relevant type of motion (in this case, intrinsic motion) was familiar and performed by the same actor as at encoding in the old items but unfamiliar in the new items.

As in Experiment 2, participants were instructed to attend to either intrinsic or extrinsic motion at encoding and were not instructed to remember which actor had performed each motion. To enforce the instruction to attend to the relevant type of motion, after viewing each encoding item, we had participants complete the same rating task as was used in Experiment 2. At test, participants were reminded of the relevant type of motion. Participants in the old–conjunction discrimination conditions were instructed that, in some of the test items, an actor would be seen exhibiting the same motion that she had performed at encoding, whereas in other test items, an actor would be seen exhibiting a motion that had been performed by a different actor at encoding. We instructed these participants that they should only respond "yes" to a test item if the relevant type of motion was being performed by the same actor who had performed this motion earlier.

We instructed participants in the old–new discrimination conditions that in some of the test items the relevant type of motion would be identical to one seen at encoding, whereas in other test items, the relevant type of motion would be new. We further instructed participants that although the relevant type of motion would be familiar in some of the test items, the irrelevant type of motion would always be new. Participants were instructed to respond "yes" as long as the relevant type of motion was familiar, regardless of any changes in the irrelevant type of motion.

Design. The dependent variable in this experiment involved the proportions of "yes" and "no" responses to the different types of recognition items, as well as participants' confidence in those responses. The independent variables for this analysis were item type (old vs. lure), manipulated within subjects, motion type (extrinsic motion vs. intrinsic motion), manipulated between subjects, and discrimination type (old–conjunction vs. old–new), also manipulated between subjects.

Results

Recognition judgments. The mean proportions of "yes" responses to old and lure items in the four different conditions are presented in Figure 5. An ANOVA on these proportions with item type (old vs. lure), motion type (intrinsic motion vs. extrinsic motion), and discrimination type (old–conjunction vs. old–new) as independent variables revealed a main effect of item type, $F(1, 124) = 345.33$, $MSE = 0.03$, $p < .001$, $\eta_p^2 = 0.74$, indicating successful discrimination of old and lure items. There was also an interaction of item type and discrimination type, $F(1, 124) = 22.82$, $MSE = 0.03$, $p < .001$, $\eta_p^2 = 0.16$, indicating better discrimination of old and lure items in the old–new discrimination conditions than in the old–conjunction discrimination conditions. Furthermore, there was a significant main effect of discrimination type, $F(1, 124) = 40.93$, $MSE = 0.04$, $p < .001$, $\eta_p^2 = 0.25$, with a lower overall rate of "yes" responding in the old–new discrimination conditions than in the old–conjunction discrimination conditions. These effects were moderated, however, by a significant three-way interaction of item type, discrimination type, and motion type, $F(1, 124) = 4.95$, $MSE = 0.03$, $p = .03$, $\eta_p^2 = 0.04$. Follow-up t tests revealed that participants were significantly more likely to falsely recognize extrinsic conjunction items than to falsely recognize intrinsic conjunction items, $t(62) = 2.30$, $p = .03$, replicating in a between-subjects design the principal result of

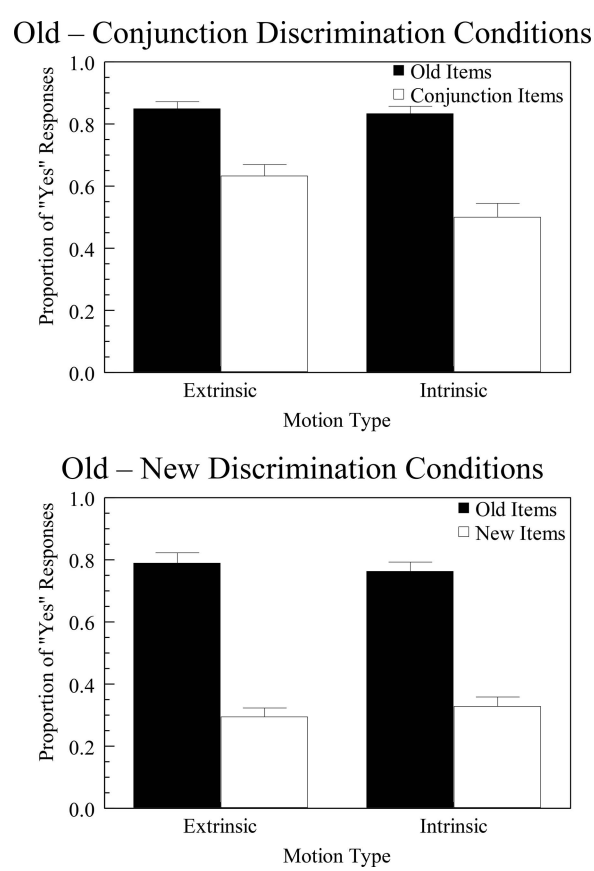

Figure 5. Proportions of "yes" responses to old and lure items in the old–conjunction and old–new discrimination conditions of Experiment 3. Error bars represent standard errors.

Experiments 1 and 2. There were no significant differences between the two motion conditions in correct recognition of the old items, either with the old–conjunction discrimination, $t(62) = 0.47$, $p > .10$, or with the old–new discrimination, $t(62) = 0.58$, $p > .10$, and there was not a significant difference between the two motion conditions in false recognition of the new items for participants who were assigned the old–new discrimination, $t(62) = 0.81$, $p > .10$.

Modeling of receiver operating characteristics. A ROC function was constructed for each of the four conditions by relating the mean rate of acceptance of old items at each confidence level (e.g., absolutely sure yes) to the mean rate of acceptance of lure (i.e., conjunction or new) items at that same confidence level. Data from four participants (three in the old–intrinsic conjunction discrimination condition and one in the old–new intrinsic motion discrimination condition) were not included when constructing these ROC functions, three because they never used the "absolutely sure" confidence rating to justify either a "yes" or "no" response, and one who justified all responses with an "absolutely sure" confidence rating. The ROC functions for the remaining participants in the old–conjunction discrimination conditions are presented in Figure 6, whereas the ROC functions for the remaining participants in the old–new discrimination conditions are presented in Figure 7. The leftmost point on each function relates the probability of responding "absolutely sure yes" to old items to the probability of making the same response to lure items. The second leftmost point includes both "absolutely sure yes" and "pretty sure yes" responses to each item type, with each subsequent point on a function including an additional confidence level until only "absolutely sure no" responses are excluded (in the rightmost point on each function). Chance performance would be indicated by an ROC function falling along the central diagonal, whereas better than chance performance would be indicated by an ROC falling above and to the left of the central diagonal.

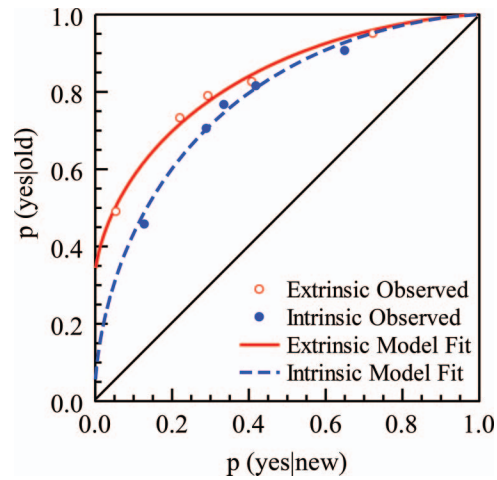

Figure 7. Receiver operating characteristic functions relating acceptance of old items to acceptance of new items at different levels of confidence in Experiment 3. The leftmost point on each function relates the probability of responding "absolutely sure yes" to old items to the probability of responding "absolutely sure yes" to new items. Each subsequent point on a function includes an additional confidence level, with the rightmost point on each function relating the probability of responding anything but "absolutely sure no" to the old items and to the new items. The solid and dashed lines indicate the best-fitting functions produced by Yonelinas's (1999) dual-process source-memory model for the extrinsic and intrinsic motion conditions, respectively. See the online article for the color version of this figure.

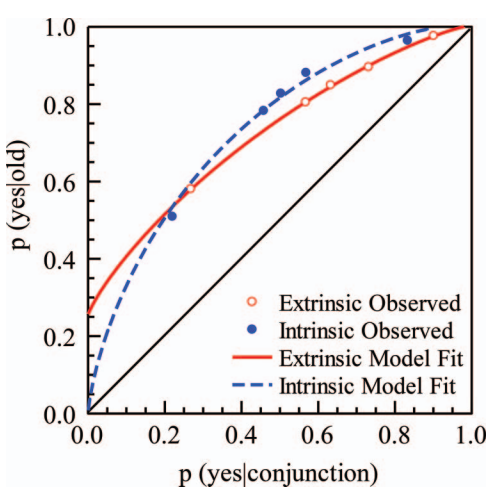

Figure 6. ROC functions relating acceptance of old items to acceptance of conjunction items at different levels of confidence in Experiment 3. The leftmost point on each function relates the probability of responding "absolutely sure yes" to old items to the probability of responding "absolutely sure yes" to conjunction items. Each subsequent point on a function includes an additional confidence level, with the rightmost point on each function relating the probability of responding anything but "absolutely sure no" to the old items and to the conjunction items. The solid and dashed lines indicate the best-fitting functions produced by Yonelinas's (1999) dual-process source-memory model for the extrinsic and intrinsic motion conditions, respectively. See the online article for the color version of this figure.

Discrimination of old and lure items solely on the basis of familiarity (represented by d') would be expected to lead to an ROC function that is symmetrical and normally distributed with respect to the baseline provided by the central diagonal.[1] For example, the dashed function in Figure 7, representing discrimination of old and new intrinsic motion items, exhibits the bell-shaped pattern characteristic of a normal distribution.

Recollection of having seen at least some of the old items previously (represented by R_t), however, would be expected to

[1] A symmetrical, normally distributed receiver operating characteristics (ROC) function requires that the familiarity levels of the old items and the familiarity levels of the lure items both be normally distributed and of equal variance. Dual-process theories of recognition memory (e.g., Yonelinas, 1999) assume such distributions of familiarity values, with any deviations from symmetrical, normally distributed ROC functions providing evidence for an alternative memory process (e.g., recollection). Other theories of recognition memory allow for the possibility of old and lure distributions of unequal variances and attempt to account for memory performance in terms of a single memory process (see, e.g., Wixted, 2007). It is not the goal of this research to adjudicate between dual-process theories of recognition memory and unequal-variance signal detection models, and it may be possible to interpret the present results in terms of either framework. To the extent that a sensible interpretation of the present results can be constructed using the assumptions of the dual-process theory, however, this may be taken as evidence of the utility of this approach.

lead to an elevation of the left side of the ROC function, if one assumes that this recollection leads to high confidence acceptance of those old items. For example, the solid function in Figure 7, representing discrimination of old and new extrinsic motion items, exhibits an elevation on the left-hand side when compared with the symmetrical distribution provided by the old–new intrinsic motion ROC, suggesting that participants in the old–new extrinsic motion discrimination condition were able to recollect having seen some of the old items previously and thus to accept them at the highest level of confidence.

Finally, recollection of having seen the motion in a conjunction item performed by a different actor earlier (represented by R_l), would be expected to lead to a leftward movement of the upper right-hand portion of an ROC function, if one assumes that this recollection leads to high confidence rejection of those conjunction items. For example, although the dashed function in Figure 6, representing discrimination of old and intrinsic conjunction items, is for the most part symmetrical, there is a slight leftward movement of the upper right-hand portion of the function. This suggests that participants in this condition may sometimes have been able to recollect having seen the intrinsic motion in a conjunction item performed by a different actor earlier (although as will be seen below, this recollection may have occurred quite rarely). This recollection would allow participants to confidently reject the possibility that they had seen the present actor perform this same motion earlier (because each motion was performed by only one actor at encoding).

Fitting Yonelinas's (1999) dual-process source-memory model to the ROC functions presented in Figures 6 and 7 provides a way of quantifying the influences of familiarity and recollection on discrimination performance in the four conditions. The best-fitting set of parameters for each condition are presented in Table 1. As can be seen in Table 1, the d' parameter is higher for the old–intrinsic conjunction discrimination than for the old–extrinsic conjunction discrimination. This finding is consistent with the theory of unitized representations of intrinsic motion information and identity information, allowing one to discriminate old and new combinations of actors and intrinsic motions on the basis of the familiarity of those combinations. In contrast, the R_t parameter is higher for the old–extrinsic conjunction discrimination than for the old–intrinsic conjunction discrimination. This finding is consistent with the theory of independent but associated representations of extrinsic motion information and identity information. In particular, the presentation of an old item involving a particular actor performing a particular extrinsic motion at test may cause one to retrieve a previously established association between that same actor and extrinsic motion, leading to the phenomenological experience of recollection of having previously seen that same combination of actor and extrinsic motion. The R_l parameter is quite low in both conditions, indicating that when participants were presented with a conjunction item, they were unlikely to recollect having previously seen a different actor perform the same motion earlier, which would have allowed them to reject the conjunction item with high confidence.

A comparison of parameter estimates for the old–new discrimination conditions reveals that the two conditions yielded quite similar d' parameters. Thus, participants in the two conditions performed quite comparably at using familiarity to distinguish old and new examples of the relevant type of motion. The R_t parameter remains higher for the old–new extrinsic motion discrimination than for the old–new intrinsic motion discrimination, however, indicating that the familiarity signal emanating from the old items was frequently supplemented by a phenomenological experience of recollection, stemming from the retrieval of a previously established association between the same actor and extrinsic motion. Thus, although performance at making old–new recognition judgments was quite comparable in the two conditions, participants in the old–new extrinsic motion discrimination condition were more confident in their acceptance of the old items because of their greater likelihood of recollecting having seen those same items earlier.

Table 1
Estimates of Familiarity and Recollection in Experiments 3 and 4

Variable	Parameter			SSE
Experiment 3				
Discrimination condition	d'	R_t	R_l	
Old–intrinsic conjunction	0.80	0.00	0.08	.0008
Old–extrinsic conjunction	0.44	0.26	0.02	<.0001
Old–new intrinsic motion	1.06	0.04		.0007
Old–new extrinsic motion	0.97	0.33		.0007
Experiment 4				
Discrimination condition	d'	R_t	R_l	
Old–intrinsic conjunction	0.66	0.00	0.00	.0002
Old–extrinsic conjunction	0.10	0.21	0.00	.0001
Old–new intrinsic motion	1.56	0.00		.0004
Old–new extrinsic motion	0.91	0.00		.0004

Note. d' = distance between the means of the familiarity distributions of the old and lure items, as expressed in standard deviation units. R_t = probability of recollecting having seen the motion in an old item performed by the same actor (i.e., the target actor) earlier. R_l = probability of recollecting having seen the motion in a conjunction item performed by a different actor earlier. R_l parameters were not estimated for the old–new discrimination conditions because the lure items involved motions not seen previously in the experiment, and thus one would presumably not recollect having seen a different actor perform those motions earlier. SSE = sum of squared errors of the estimates of both the old and lure items for all five points on the receiver operating characteristics function.

Discussion

The results of Experiment 3 provide further support for the theory that intrinsic motion representations are unitized with information about the identities of the actors performing those motions, whereas extrinsic motions are represented separately from identity information. In particular, participants were more successful at discriminating old items from novel conjunctions of familiar actors and intrinsic motions than at discriminating old items from novel conjunctions of familiar actors and extrinsic motions. Moreover, modeling of ROC functions using Yonelinas's (1999) dual-process source-memory model yielded a higher familiarity estimate for the old–intrinsic conjunction condition than for the old–extrinsic conjunction condition. This result is consistent with the notion of unitized representations of intrinsic motion information with actor information, allowing one to distinguish old and conjunction items on the basis of the familiarity of the actor/intrinsic motion combination.

In contrast, modeling revealed a higher estimate for the likelihood of recollecting old items in the old–extrinsic conjunction

condition than in the old–intrinsic conjunction condition. This result is consistent with the notion of separate representations of extrinsic motion information and actor information, thus requiring the retrieval of a previously established association between an actor and an extrinsic motion to discriminate an old item from a novel conjunction of a familiar actor and extrinsic motion. This retrieval may result in a phenomenological experience of recollection of having seen that same actor perform that same extrinsic motion earlier, leading one to accept the old items with high confidence. In the absence of such recollection, however, participants in the old–extrinsic conjunction condition had greater difficulty than did participants in the old–intrinsic conjunction condition at distinguishing old items from conjunction items on the basis of familiarity.

Experiment 4

The results of Experiments 1–3 are consistent with the theory that intrinsic motions are represented together with identity information in unitized representations, whereas extrinsic motions are represented separately from identity information, requiring one to associate these separate representations to remember which people followed which paths. A possible alternative interpretation of these results, however, is that participants associated actors not with specific paths but rather simply with the particular environment in which they had appeared. This interpretation is possible because only one path was taken in each environment. Thus, when presented with a test event involving an actor in a particular environment, if one could recollect having previously seen that same actor in that same environment, one could conclude with certainty that the actor had previously taken the same path within that environment. Participants could thus potentially have distinguished between old and extrinsic conjunction events without recollecting the exact path that an actor had followed within a particular environment.

Extrinsic motions by definition involve particular paths (e.g., around, past) in relation to particular environmental landmarks (e.g., a park bench, a statue) and thus remembering the landmarks with which an actor had appeared is certainly an important part of remembering the extrinsic motions that the actor had performed. Experiment 4 was designed to test whether participants can also remember the exact path taken by an actor in relation to an environmental landmark, and if so, whether this ability is dependent upon familiarity or recollection. To perform this test, we filmed a new set of video clips with actors taking two different paths with respect to each of a number of environmental landmarks. As in Experiments 1–3, each actor also exhibited a particular intrinsic motion while following these paths.

Participants in the old–extrinsic conjunction discrimination condition were later tested on their ability to distinguish old events from conjunction events in which an actor appeared in the same environment as before but now taking a path that had previously been taken by a different actor in relation to the landmark feature appearing in that environment. Participants in the old–intrinsic conjunction discrimination condition were again tested on their ability to distinguish old events from conjunction events in which an actor exhibited an intrinsic motion that had previously been exhibited by a different actor. Estimates of familiarity and recollection were again computed on the basis of participants' recognition responses and subsequent confidence ratings. If the division of labor theory of Kersten (1998a) is correct, participants should be able to discriminate old and intrinsic conjunction items on the basis of familiarity, whereas distinguishing old and extrinsic conjunction items should require one to recollect which path an actor had previously taken within a particular environment.

Method

Participants. One hundred forty-four undergraduates enrolled in general psychology classes received course credit for participation in this experiment.

Stimuli and procedure. A new set of 122 video clips was filmed, involving 10 actors performing a total of 50 different extrinsic motions and 50 different intrinsic motions. Actors followed two different paths in each of 25 locations to create the 50 different extrinsic motions. For example, actors were filmed both going up and going down the same staircase. Each participant viewed at encoding 38 different video clips involving 38 different intrinsic motions and 38 different extrinsic motions. Participants were instructed to attend to either extrinsic or intrinsic motions and made a rating for each video clip that encouraged attention to the relevant type of motion as in Experiments 2 and 3. The first item and last item in the encoding list were identical for all participants. These items served as primacy and recency fillers, and memory for these items was not tested. The remaining 36 video clips were presented in a unique random order for each participant.

Participants returned one week later to be tested on their memory for the video clips. As in Experiment 3, some participants were tested on their ability to distinguish old items from conjunction items. Participants in the old–intrinsic conjunction discrimination condition were tested on their ability to distinguish 12 old items from 12 conjunction items, in which an actor followed the same path that she had taken earlier but performing an intrinsic motion that had previously been performed by a different actor. Participants in the old–extrinsic conjunction discrimination condition, on the other hand, were tested on their ability to distinguish 12 old items from 12 conjunction items in which an actor appeared in the same location in which she had appeared earlier, performing the same intrinsic motion that she had performed earlier but following a path that had previously been taken by a different actor in that same location. For example, if Actor 1 had been seen crawling around a chair and Actor 2 had been seen doing lunges as she went past the chair, an extrinsic conjunction item would have involved Actor 1 crawling past the chair. Three different encoding and retrieval lists were constructed for each discrimination condition, such that a given item served as an old item on one list and a conjunction item on a second list, whereas it did not appear on the third list.

Other participants were tested on their ability to distinguish old items from items involving new intrinsic and extrinsic motions. Participants in the old–new intrinsic motion discrimination condition were tested on their ability to distinguish 12 old items from 12 items in which an actor followed the same path that she had taken earlier, but performing an intrinsic motion that had not been seen earlier in the experiment. Participants in the old–extrinsic conjunction discrimination condition, on the other hand, were tested on their ability to distinguish 12 old items from 12 items in which an actor appeared in the same location in which she had appeared

earlier, performing the same intrinsic motion that she had performed earlier but following a path that had not previously been taken in that location. Three different encoding and retrieval lists were again constructed for each discrimination condition, such that a given item served as an old item on one list and a new item on a second list, whereas it did not appear on the third list.

Because the discrimination of old and new paths within the same location was expected to be much more difficult than discriminating paths in two different locations, as was tested in Experiment 3, the possibility of floor effects in this condition was of greater concern than was the possibility of ceiling effects. In order to increase the overall level of performance in the old–new discrimination conditions, the irrelevant type of motion (i.e., the type of motion to which participants were not instructed to attend) was always old in Experiment 4, in contrast to Experiment 3, in which the irrelevant type of motion was always new for participants in the old–new discrimination conditions. Participants in the old–new discrimination conditions were thus tested on their ability to distinguish items that were identical to items seen at encoding from items in which either the intrinsic or extrinsic motion was new, whereas the other irrelevant type of motion was old.

Design. The dependent variable in this experiment involved the proportions of "yes" and "no" responses to the different types of recognition items, as well as participants' confidence in those responses. The independent variables for this analysis were item type (old vs. lure), manipulated within subjects, motion type (extrinsic motion vs. intrinsic motion), manipulated between subjects, and discrimination type (old–conjunction vs. old–new), also manipulated between subjects.

Results

Recognition judgments. The mean proportions of "yes" responses to old and lure items in the four different conditions are presented in Figure 8. An ANOVA on these proportions with item type (old vs. lure), motion type (intrinsic vs. extrinsic), and discrimination type (old–conjunction vs. old–new) as independent variables revealed a main effect of item type, $F(1, 140) = 395.39$, $MSE = 0.02$, $p < .001$, $\eta_p^2 = 0.74$, indicating successful discrimination of old and lure items. There was also an interaction of item type and discrimination type, $F(1, 140) = 66.17$, $MSE = 0.02$, $p < .001$, $\eta_p^2 = 0.32$, indicating better discrimination of old and lure items in the old–new discrimination conditions than in the old–conjunction discrimination conditions. Furthermore, there was an interaction of item type and motion type, $F(1, 140) = 37.22$, $MSE = 0.02$, $p < .001$, $\eta_p^2 = 0.21$, with greater discrimination of old and lure items in the intrinsic motion conditions than in the extrinsic motion conditions. In particular, participants in the intrinsic motion conditions were more likely than participants in the extrinsic motion conditions to correctly recognize the old items, $t(142) = 2.54$, $p = .01$, whereas participants in the intrinsic motion conditions were less likely than participants in the extrinsic motion conditions to falsely recognize the lure items, $t(142) = 3.76$, $p < .001$. This overall advantage to the intrinsic motion conditions likely reflects the greater difficulty associated with discriminating two different paths within the same location in the extrinsic motion conditions. Because the intrinsic motion conditions outperformed the extrinsic motion conditions on not only the old–conjunction discrimination but also the old–new discrimination, the three-way interaction of item type, motion type, and discrimination type was not significant, $F(1, 140) = 2.50$, $MSE = 0.02$, $p > .10$, $\eta_p^2 = 0.02$. Modeling was thus necessary to determine whether the intrinsic motion conditions outperformed the extrinsic motion conditions on all aspects of memory performance or whether the extrinsic motion conditions continued to exhibit a greater likelihood of recollection.

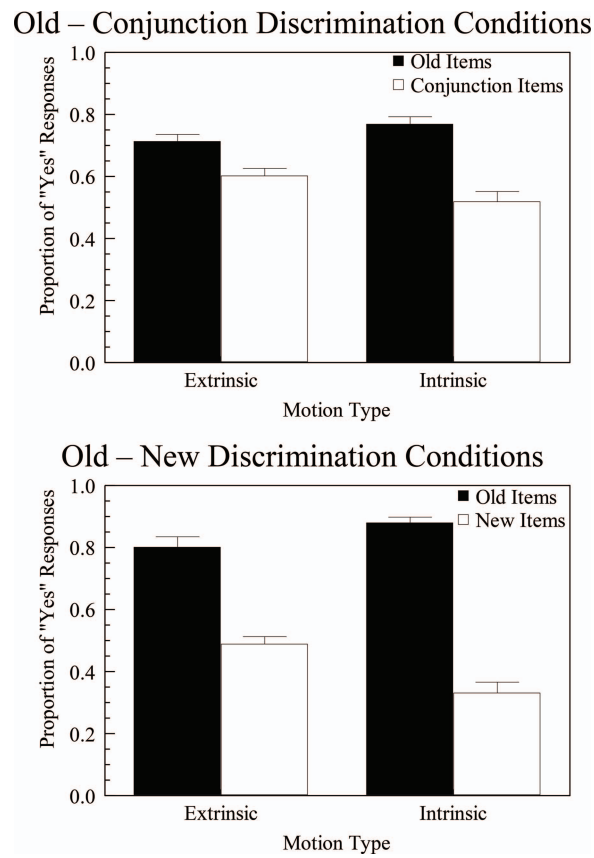

Figure 8. Proportions of "yes" responses to old and lure items in the old–conjunction and old–new discrimination conditions of Experiment 4. Error bars represent standard errors.

Modeling of ROCs. ROC functions were again constructed for each of the four conditions. Data from eight participants (three in each of the old–new discrimination conditions and one in each of the old–conjunction discrimination conditions) were not included when constructing ROC functions because these participants never used the "absolutely sure" confidence rating to justify either a "yes" or "no" response. The ROC functions for participants in the old–conjunction discrimination conditions are presented in Figure 9, whereas the ROC functions for participants in the old–new discrimination conditions are presented in Figure 10.

Yonelinas's (1999) dual-process source-memory model was again fit to the data to quantify the influences of familiarity and recollection on discrimination performance in the four conditions. The best-fitting set of parameters for each condition are presented in Table 1. As can be seen in Table 1, the d' parameter is again higher for the old–intrinsic conjunction discrimination than for the old–extrinsic conjunction discrimination, consistent with the theory of unitized representations of intrinsic motion information and

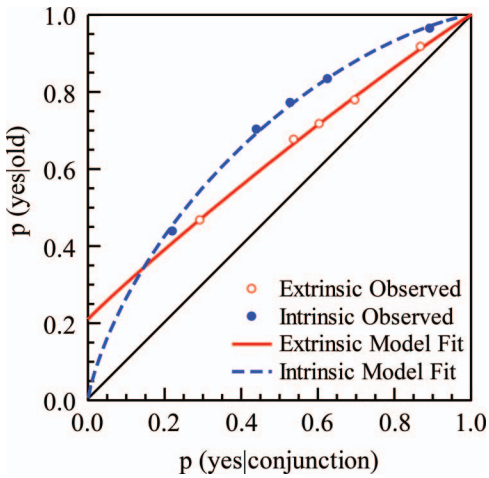

Figure 9. Receiver operating characteristic functions relating acceptance of old items to acceptance of conjunction items at different levels of confidence in Experiment 4. The leftmost point on each function relates the probability of responding "absolutely sure yes" to old items to the probability of responding "absolutely sure yes" to conjunction items. Each subsequent point on a function includes an additional confidence level, with the rightmost point on each function relating the probability of responding anything but "absolutely sure no" to the old items and to the conjunction items. The solid and dashed lines indicate the best-fitting functions produced by Yonelinas's (1999) dual-process source-memory model for the extrinsic and intrinsic motion conditions, respectively. See the online article for the color version of this figure.

identity information. In contrast, the R_t parameter is higher for the old–extrinsic conjunction discrimination than for the old–intrinsic conjunction discrimination, consistent with the theory of independent but associated representations of extrinsic motion information and identity information. The R_I parameter is estimated at zero in both conditions, indicating that when participants were presented with a conjunction item, they were unlikely to recollect having previously seen a different actor perform the same motion earlier.

A comparison of parameter estimates for the old–new discrimination conditions reveals a higher d' parameter for the intrinsic motion condition than for the extrinsic motion condition, likely reflecting the greater difficulty associated with discriminating an old and a new path within the same location in the extrinsic motion condition. The R_t parameters were estimated at 0 for both conditions, suggesting that neither condition used recollection to discriminate old and new items. The absence of influences of recollection in either condition may reflect the use of old rather than new examples of the irrelevant type of motion when constructing the test items in Experiment 4. Old items were thus identical to items seen at encoding, whereas new items involved a new example of one of the two motion features, leading to a stronger familiarity signal for the old than for the new items and perhaps discouraging the use of a more effortful recollection strategy.

Inferential statistics on parameter estimates. Familiarity and recollection parameters have thus far only been computed on the basis of average ROC functions over all of the participants in a given discrimination condition. This approach does not allow one to perform inferential statistics on these parameter estimates, because there is only a single estimate of each parameter for each discrimination condition and thus no measure of variability in parameter estimates. To perform inferential statistics on the parameter estimates from Experiment 4, we aggregated participants not at the level of entire discrimination conditions but rather at the level of the different retrieval lists used for each discrimination condition. In particular, because there were three different lists of retrieval items in Experiment 4, with those same lists of items rotated through the different discrimination conditions, those three retrieval lists can be treated as three independent replications of the comparisons between the different discrimination conditions. An ROC function could thus be constructed for each retrieval list for each of the discrimination conditions, allowing one to calculate the best-fitting familiarity and recollection parameters for each of those ROC functions. Repeated-measures comparisons could then be performed on the familiarity and recollection parameters for the different lists, given that those same lists were repeated in the different conditions of the experiment. Most notably, we could examine whether the same list resulted in significantly different familiarity and recollection parameters when used in the context of an old–intrinsic conjunction discrimination and in the context of an old–extrinsic conjunction discrimination.

A comparison of parameter estimates for the old–conjunction discrimination conditions revealed significantly higher d' parameters in the intrinsic motion condition ($M = 0.53$, $SD = 0.16$) than in the extrinsic motion condition ($M = 0.02$, $SD = 0.19$), $t(2) = 11.83$, $p = .007$, consistent with the use of unitized representations of intrinsic motion and identity information to discriminate old and intrinsic conjunction items on the basis of familiarity. R_t parameters on the other hand were significantly higher in the extrinsic

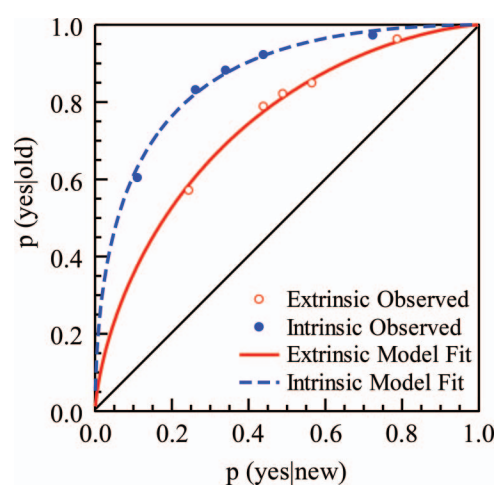

Figure 10. Receiver operating characteristic functions relating acceptance of old items to acceptance of new items at different levels of confidence in Experiment 4. The leftmost point on each function relates the probability of responding "absolutely sure yes" to old items to the probability of responding "absolutely sure yes" to new items. Each subsequent point on a function includes an additional confidence level, with the rightmost point on each function relating the probability of responding anything but "absolutely sure no" to the old items and to the new items. The solid and dashed lines indicate the best-fitting functions produced by Yonelinas's (1999) dual-process source-memory model for the extrinsic and intrinsic motion conditions, respectively. See the online article for the color version of this figure.

motion conditions ($M = 0.24$, $SD = 0.07$) than in the intrinsic motion conditions ($M = 0.09$, $SD = 0.12$), $t(2) = 4.61$, $p = .04$, consistent with the use of recollection of having previously seen the same actor perform the same extrinsic motion to discriminate old items from extrinsic conjunction items. R_l parameters did not significantly differ in the extrinsic motion ($M = 0.02$, $SD = 0.02$) and intrinsic motion ($M = 0.03$, $SD = 0.05$) conditions, $t(2) = 0.26$, $p > .10$.

A comparison of parameter estimates for the old–new discrimination conditions revealed a trend that approached significance for higher d' parameters in the intrinsic motion conditions ($M = 1.54$, $SD = 0.24$) than in the extrinsic motion conditions ($M = 0.93$, $SD = 0.15$), $t(2) = 3.24$, $p = .08$. R_t parameters on the other hand did not significantly differ in the extrinsic motion ($M = 0.01$, $SD = 0.02$) and intrinsic motion ($M = 0.05$, $SD = 0.08$) conditions, $t(2) = 0.80$, $p > .10$.

Discussion

The results of Experiment 4 are consistent with those of Experiments 1–3 in showing that memory for the extrinsic motions exhibited by an actor is dependent on recollection. Successful memory for extrinsic motions in this experiment required one to remember not only the particular landmarks with which an actor had appeared but also the particular paths an actor had followed with respect to these landmarks. This was a more difficult discrimination than the corresponding discriminations in Experiments 1–3, in which landmark information could be used to distinguish old and lure items in the extrinsic motion conditions in the absence of any knowledge of how an actor had moved in relation to those landmarks. Performance was thus poorer with extrinsic motions than with intrinsic motions in Experiment 4, not only in the old–conjunction discrimination conditions but also in the old–new discrimination conditions, complicating the interpretation of the ANOVA results. In particular, differences in the salience or discriminability of the extrinsic and intrinsic motions used in Experiment 4 appeared to accompany any differences in participants' abilities at associating the two types of motion with the actors who performed them. If the results of Experiment 4 simply reflected the greater salience or discriminability of the intrinsic motions than of the extrinsic motions, however, then the intrinsic motion conditions would be expected to outperform the extrinsic motion conditions on all aspects of memory performance. In contrast to this prediction, applying Yonelinas's (1999) dual-process source-memory model to the present results revealed that participants were more successful at using recollection to discriminate old and extrinsic conjunction items than to discriminate old and intrinsic conjunction items. Thus, if one accepts the assumptions of Yonelinas's model, this result provides support for our theory that remembering which people followed which paths requires one to retrieve associations between independently represented identity and extrinsic motion information. In contrast, participants again exhibited greater use of familiarity to discriminate old and intrinsic conjunction items than to discriminate old and extrinsic conjunction items, consistent with our theory that intrinsic motion information is represented conjointly with identity information in unitized memory representations.

General Discussion

The results of four experiments are thus consistent in showing that people are better at remembering which actor had performed a particular intrinsic motion than at remembering which actor had performed a particular extrinsic motion. Experiment 1 demonstrated that when participants were explicitly instructed to remember both types of motions, as well as the identities of the people who performed them, they were more successful at remembering pairings of actors with intrinsic motions than with extrinsic motions.

Experiment 2 replicated this finding even when participants were only instructed to remember the motions (either intrinsic or extrinsic) and were not instructed to remember which person had performed each motion. This finding suggests that when participants were instructed to remember intrinsic motions, they automatically encoded them in terms of the appearances of the body parts that carried out those motions. Thus, when later presented with a different actor performing those same motions, this stimulus failed to match the previously encoded motion representation, leading participants to correctly reject those motions. In contrast, when instructed to remember extrinsic motions, participants may have encoded them in a more abstract fashion, such that when they were later presented with a different actor performing those same motions, they were more likely to falsely accept the event as having been seen before.

The results of Experiment 3 were fit with Yonelinas's (1999) dual-process source-memory model, revealing that participants relied largely on familiarity when discriminating old and new combinations of familiar actors and intrinsic motions. This result is consistent with the notion of unitization of target and source features, in this case motion features with features of the person who carried out those motions. In contrast, the role of familiarity was diminished and the role of recollection was increased when the model was applied to a condition in which participants had to distinguish old and new combinations of familiar actors and extrinsic motions.

Finally, the results of Experiment 4 suggest that participants relied on recollection not only when they had to remember the landmarks in relation to which an actor had moved but also the particular paths that the actor had followed with respect to those landmarks. This interpretation again derives from applying Yonelinas's (1999) model to the present results, and thus if one accepts the assumptions of this model, the results of Experiment 4 provide further support for the theory that memory for extrinsic motions (i.e., particular paths in relation to particular landmarks) involves independent but associated representations of motion and identity information. In contrast, participants again relied on familiarity when they were asked to remember which intrinsic motions an actor had performed, consistent with the unitization of intrinsic motion information with identity information.

Even if one relies solely on the ANOVA results and remains agnostic about the further assumptions of Yonelinas's model, the present results are consistent in showing that remembering the scene context in which an actor had appeared is more difficult than remembering the specific intrinsic motions that the actor had performed, even when the baseline salience of the scene information and intrinsic motion information are equated. Given that extrinsic motions are defined with respect to external landmark

information present only in the background scene, these results are thus consistent with the notion that remembering which extrinsic motions an actor had performed invokes different memory processes (e.g., recollection) than those involved in remembering which intrinsic motions an actor had performed (e.g., familiarity).

Implications for Person Representations

The present results suggest that representations of the intrinsic motions of a person include information both about the appearances of the various parts of that person and how those parts move in relation to one another during locomotion. Thus, when later presented with this same person exhibiting the same intrinsic motion as before, this stimulus will match one of these previously established unitized representations of identity and intrinsic motion information, leading to a feeling of familiarity for the stimulus. If one later sees this same person exhibiting a different intrinsic motion, or a new person exhibiting a familiar intrinsic motion, these stimuli will fail to fully match any of these unitized representations, leading to reduced familiarity.

A likely brain locus for these unitized representations of identity information and intrinsic motion information is the superior temporal sulcus (STS). This region has been associated with "biological motion" perception in the monkey visual system, with some cells responding to the movements of individual body parts, such as arms, legs, hands, and fingers, and others responding to the movements of whole, moving figures (Oram & Perrett, 1994, 1996; Perrett et al., 1985). Neuroimaging studies with humans have similarly revealed a sensitivity of this area to human body movements. Of particular relevance to the present study, Beauchamp, Lee, Haxby, and Martin (2002) observed a greater response in the STS to articulated human motions (e.g., jumping jacks) rather than unarticulated motions (e.g., rotating and translating), suggesting that STS neurons were responding preferentially to the relative motions of the various parts of the human body (i.e., intrinsic motions).

STS neurons may be particularly well-suited for representing intrinsic motions because of their ability to integrate form and motion information. For example, Jellema, Baker, Wicker, and Perrett (2000) revealed that some neurons in the monkey STS responded to arm (but not leg) movements in a particular direction, whereas others responded to leg (but not arm) movements in a particular direction. Furthermore, Beauchamp, Lee, Haxby, and Martin (2003) found that the human STS responded more strongly to full video displays of human motion than to point-light versions of those displays, suggesting that these areas responded to both the form and motion information in the full video displays. Because intrinsic motions involve particular body parts moving in particular ways with respect to the body as a whole, this responsiveness to both form and motion information is crucial.

A prior study that specifically examined the role of the STS in memory for people and their actions was conducted by Kable and Chatterjee (2006). Using an fMRI adaptation paradigm, they found that posterior regions of the STS exhibited reduced activation when the same action was repeated, suggesting that these regions were involved in processing this type of action information. They noted that this neural adaptation occurred both when an action was performed by the same actor as before and when it was performed by a new actor, suggesting some ability of these regions to abstract over the identity of the actor involved. Detailed inspection of their results, however, suggests that adaptation was greater when the action was performed by the same actor as before than when it was performed by a new actor. Thus, these STS regions may be sensitive to both identity and motion information, consistent with the notion of unitized representations of these two types of information.

Although Kable and Chatterjee (2006) did not examine the distinction between extrinsic and intrinsic motions, they did distinguish between "transitive" and "intransitive actions," finding no differences in brain activations between these two classes of actions. Intransitive actions (e.g., raise hand, walk, jumping jack) involved different movements of an individual person in the context of an unvarying and unrelated background environment. These actions thus would appear to correspond closely with the category of intrinsic motions. Transitive actions (e.g., brush hair, sweep, hammer) on the other hand involved external objects. Although the presence of an external object might suggest an extrinsic component to these actions, these objects were largely tools that functioned as extensions of the actor's body with the actor moving his or her body in characteristic ways to match the function of the tool (e.g., brushing one's hair involves particular movements of one's hands in relation to one's head while holding a brush). Thus, it is possible that the STS adaptation observed in response to these actions reflects the intrinsic component of these actions, just as with the intransitive actions.

If regions of the STS indeed respond to specific combinations of identity and intrinsic motion information, how might these STS responses play a role in explicit memory judgments, such as were used in the present experiments? The present experiments suggest that participants were able to differentiate familiar from unfamiliar combinations of actors and intrinsic motions on the basis of a familiarity signal. Diana et al. (2008) have proposed that the perirhinal cortex, a region of the medial temporal lobe, supports such familiarity-based recognition of unitized representations of item and source information. Perirhinal cortex receives direct projections from STS (Suzuki & Amaral, 1994), and thus it is quite plausible that if the STS is indeed sensitive to particular combinations of actors and intrinsic motions, this STS activity could modulate the familiarity response of the perirhinal cortex.

Although the present results suggest the existence of unitized representations of identity information with intrinsic motion information, possibly mediated by the STS, it is likely that static cues to identity are represented separately from motion information at other levels of the visual system. For example, the face fusiform area responds strongly to static human faces (Kanwisher, McDermott, & Chun, 1997), whereas the extrastriate body area and lateral fusiform gyrus appear to respond to the sight of the entire human body, regardless of whether it is moving or stationary (Beauchamp et al., 2002; Downing, Jiang, Shuman, & Kanwisher, 2001). These areas may thus specialize in processing the human form rather than human motion. In fact, when participants in the present experiments were instructed to remember the extrinsic motions performed by each actor, they may have done so by associating independent representations of extrinsic motion and static form information (e.g., what the face and/or body of each actor looked like). In contrast, it is not clear whether intrinsic motion information can be represented independently of form information. Because intrinsic motions involve movements of particular body

parts in relation to one another, such motions may be difficult to define without reference to the body parts themselves. A representational scheme that combines static form information with movement information may thus be the most natural way of describing such motions.

Implications for Event Representations

The present results suggest that events are represented by associations among the various actors and objects taking part in an event, the scene in which the event takes place, including the various landmarks situated within that scene, and the interactions of the actors and objects with one another and with those landmarks (see Urgolites & Wood, 2013, for a related account). These associations would allow people to use one or more of these different types of information to retrieve the other, associated information, allowing one to bring to mind the entire event. This retrieval of previously established associations may lead to a phenomenological experience of recollection, allowing one to recognize the event with high confidence.

Representing an event in memory may require one to associate the various components of the event because those components are represented in geographically disparate parts of the brain. Person and object information may be represented in various regions of the ventral stream of information processing (i.e., the "what" stream; see Ungerleider & Mishkin, 1982), culminating in perirhinal cortex (Eichenbaum & Lipton, 2008). Scene information, on the other hand, may be represented in various regions of the dorsal stream (i.e., the "where" stream), with these regions projecting to the parahippocampal cortex. In fact, Epstein and Kanwisher (1998) have identified a region of parahippocampal cortex that responds selectively to scene information, leading them to dub this region the parahippocampal place area. Object and scene information remain segregated as they enter the hippocampal region (Eichenbaum & Lipton, 2008). Thus, hippocampal mediation may be necessary to associate target objects, represented in perirhinal cortex, with information about the contexts in which those objects appeared, represented in parahippocampal cortex (Diana et al., 2008).

Remembering the specific path taken by an object or person within a particular context may recruit regions of the parietal and frontal lobes typically associated with locating objects in space (e.g., the superior and inferior parietal lobules and frontal eye field; see Wu, Morganti, & Chatterjee, 2008). Because these regions of the dorsal pathway are anatomically distinct from the more ventral regions subserving knowledge of people and objects, hippocampal mediation may again be necessary to bind person information with path information. In fact, our results suggest that remembering the path a person has taken within a scene context presents a particular challenge to the human memory system. Participants had difficulty discriminating old items from extrinsic conjunction items in Experiment 4, in which extrinsic conjunction items involved an actor appearing in the same scene context in which she had appeared earlier but now following a different path within that context. Participants were more successful in Experiment 3, in which memory for the scenes in which an actor had appeared could be used to discriminate old and extrinsic conjunction items. In both cases, however, successful discrimination was associated with recollection of old items, suggesting that participants were retrieving previously established associations of actor information with extrinsic motion information (i.e., the locations in which an actor had been seen and the specific paths she had taken in those locations).

Extrinsic motion information may be represented separately from identity information because the two types of information combine for the most part interchangeably. In particular, the structure and appearance of a person or object provide minimal constraints on the extrinsic motions one can perform. For example, people, ants, and mosquitoes are all capable of descending on a recently unfolded picnic blanket even though they may use quite different intrinsic motions to get there. Because of the large number of possible combinations of objects and extrinsic motions unitized representations of these two types of information may be computationally intractable. Instead, the human memory system seems to have adopted the strategy of representing objects and extrinsic motions separately, while preserving the ability to form associations among objects and extrinsic motions that happen to be experienced together.

As another way of characterizing this distinction between extrinsic motions and intrinsic motions, intrinsic motions are typically not limited to one moment in time, but rather are likely to be performed over a longer interval (e.g., "Mary is running.") and possibly habitually (e.g., "Mary runs."). In contrast, extrinsic motions can often be pinpointed to a single instant in time (e.g., "Mary entered the room."). Because episodic memory mechanisms such as the hippocampus are thought to locate an event in both space and time (Eichenbaum, 2013) it is reasonable to expect that the representation of extrinsic motions would recruit these episodic memory mechanisms to a greater extent than would the representation of intrinsic motions. Intrinsic motions, on the other hand, may be represented together with other semantic knowledge regarding the more stable, enduring properties of objects.

The theory that extrinsic motions are represented separately from object information in episodic memory representations, whereas intrinsic motions are represented together with more stable semantic knowledge about objects, may explain why extrinsic motion information is typically considered to be the most central feature of an event, whereas intrinsic motion information is optional. Evidence for the primacy of extrinsic motion information in event representations comes from research in linguistics documenting the different ways of describing events in different languages. Most notably, Talmy (1985) documented typological differences between *satellite*-framed languages (S-languages, e.g., Germanic languages, Russian, Mandarin) and *verb*-framed languages (V-languages, e.g., Romance languages, Hebrew, Japanese) in their treatments of motion events. In S-languages, the path taken by the subject with respect to a ground object (i.e., the extrinsic motion of the subject) is typically conveyed by a preposition or other satellite phrase, leaving the verb to convey other types of information, typically intrinsic motion information. For example, in the English sentence "The man walked into the building," the man's extrinsic motion is conveyed by the prepositional phrase (i.e., "into the building"), whereas the intrinsic motion he uses to get there is conveyed by the verb (i.e., "walked").

In V-languages, the verb is typically used to describe the extrinsic motion of the subject. Thus, if the speaker also wanted to convey the intrinsic motion that the subject uses to achieve this extrinsic motion, this would have to be conveyed by an adverbial

element. For example, a literal translation of the above English sentence into Spanish would be "El hombre entró al edificio caminando," or "The man entered the building walking." Because this adverbial element adds to the length of the description of this event, however, Spanish speakers will often omit explicit mention of the intrinsic motion of the subject unless it is particularly important to the message they are trying to convey (Naigles, Eisenberg, Kako, Highter, & McGraw, 1998). In contrast, because intrinsic motion information essentially "comes for free" for speakers of S-languages (e.g., compare "The man walked into the building" vs. "The man went into the building."), English speakers are more likely than Spanish speakers to provide this information, both in spoken language and in written text (Slobin, 2004).

Speakers of S-languages and V-languages are thus equally likely to mention the extrinsic motion of the moving figure in an event (albeit using different grammatical devices to do so), whereas speakers of S-languages are more likely than speakers of V-languages to explicitly mention the intrinsic motion. On the basis of these results, Slobin (2004) has proposed that path information (i.e., extrinsic motion) is an obligatory element of a motion event description, thus being readily conveyed and attended to by speakers of all languages, whereas information about the manner in which the figure moves along this path (i.e., its intrinsic motion) is optional, thus varying in the levels of attention accorded to it by speakers of different languages.

Consistent with this theory, Kersten et al. (2010) demonstrated that speakers of Spanish and English performed equally well in a category learning task that required attention to the extrinsic motions of novel bug-like creatures, whereas English speakers performed better than Spanish speakers when the category learning task required attention to the intrinsic motions of those creatures. Kersten et al. proposed that English speakers' frequent experience of producing and hearing intrinsic motion verbs may lead them to habitually attend to this type of information in an event. Both Spanish speakers and English speakers may attend to extrinsic motion information, however, because of the prominence given to this type of information in event descriptions in both languages.

Further evidence for the importance of extrinsic motion in event representations comes from children's early word learning. The first relational terms produced by children learning English are usually not verbs, which, as discussed above, typically refer to intrinsic motions (e.g., run, walk, crawl), but rather prepositions and verb particles (e.g., in, out, up, down), which are typically used to refer to extrinsic motions (Bowerman, 1978; Farwell, 1977; Gentner, 1982; Gopnik & Choi, 1995; McCune-Nicolich, 1981; Nelson, 1974; Smiley & Huttenlocher, 1995; Tomasello, 1987). Children learning English have been found to start using these prepositions and verb particles to convey extrinsic motions at around the same time that children learning V-languages start using extrinsic motion verbs, whereas children typically start to produce terms that convey intrinsic motions only later (Choi & Bowerman, 1991). Thus, regardless of how they are marked in the language spoken around a child, children seem to learn relational terms for extrinsic motions earlier than terms for intrinsic motions. In fact, Mandler (2004) has proposed that children form event representations around path information (i.e., extrinsic motions) even before they start producing language to describe these events, with this path information forming the basis for children's understanding of such core notions as causality and containment.

Experimental studies of children's verb learning also point to an initial universal tendency to focus on the extrinsic motions present within an event, followed only later by language-specific patterns of attention reflecting the typical uses of verbs in a child's native language. For example, Maguire et al. (2010) demonstrated that English-, Spanish-, and Japanese-speaking 2-year-olds all preferentially mapped a novel verb onto the path taken by an animated starfish with respect to a ball appearing in the center of the screen (i.e., an extrinsic motion), even though the way the starfish moved its legs (i.e., an intrinsic motion) was an equally plausible referent. Verb construals of 3- to 5-year-old children, on the other hand, revealed subtle influences of a child's native language, with English-speaking children maintaining focus on intrinsic motion more consistently over multiple trials than did either Spanish- or Japanese-speaking children. Thus, as with the data from real-world vocabulary development, these results suggest an initial focus on extrinsic motion information in children's early construals of events, followed later by increased attention to intrinsic motion when learning terms that make frequent reference to this type of motion (see Pulverman, Hirsh-Pasek, Golinkoff, Pruden, & Salkind, 2006, for related evidence).

The present results suggest a possible explanation for this pattern. In particular one may often be able to infer based on one's prior experience with the objects involved, the nature of the intrinsic motions taking place in an event, and thus this information need not be explicitly specified. For example, if the subject of a sentence is a squirrel, one can infer a scampering motion, whereas if the subject is one's friend who walks with a limp, one can infer that this friend was also limping in the event being described. Thus, if one speaks a language such as English, in which the explicit specification of intrinsic motion does not increase the complexity of a sentence, one may still mention this information, but if one speaks a language such as Spanish, one may leave it to be inferred. On the other hand, one cannot always infer where these intrinsic motions caused the subject of the sentence to travel, and thus this extrinsic motion information needs to be explicitly specified regardless of the language one speaks.

Conclusions

The present experiments provide evidence for different mechanisms underlying the association of intrinsic and extrinsic motions with information about the identities of the actors who carry out those motions. In particular, they suggest that intrinsic motions are represented conjointly with identity information in unitized memory representations. Extrinsic motions on the other hand may be represented separately from identity information, requiring an external binding mechanism to associate the two types of information. This may explain why one can identify a familiar individual on the basis of his or her distinctive walk, whereas it is more difficult to remember where that individual was seen and which direction he or she was going.

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(*Appendices follow*)

Appendix A

Extrinsic and Intrinsic Motions Used as Test Items in Experiments 1–4

Extrinsic motions	Intrinsic motions
Experiments 1, 2, and 3	
Into alcove	High-knees run
Away from soda machine	Cherry-picking jump (touch ground, jump arms up)
Out of dorm room	Jumping jacks
Into sand pit	Combat crawl (crawl on stomach)
Past map sign	Skip
Away from fountain	Walk on heels with toes pointed up
To water pipes	March
Around foosball table	Leapfrog
Down handicapped ramp	Monkey walk (briefly touching hands to ground each step)
Up outdoor staircase	Tightrope walk (arms to the sides for balance)
Into storage shed	Walk while doing pat-a-cake
Out of building	Spin
Away from fire hydrant	Somersault
Past emergency phone	Carioca (run sideways; right foot in front of left, then behind)
To bike rack	Race walk (exaggerated arm movements)
Out of restroom	Robot walk (rotate body while keeping legs stiff)
Around street sign	Shuffle feet
Up ramp in parking deck	Butt-kicks (lift feet to butt while running)
Away from dumpster	Swimming stroke
Down wooden steps	Limp
Out of tennis court	Jump
Into soccer goal	Frankenstein walk (arms stretched forward)
Into volleyball net	Running long-jump
Past sunflower statue	Lunges
Past round bench	Run with straight legs
Around wind spinner	Crab walk
Up spiral staircase	Hop
Down indoor staircase	Dance
Away from electrical box	Cartwheel
To coral statue	Walk like an Egyptian
Out of elevator	Walk while flapping like a bird
Into pool	Waltz with imaginary partner
Past large-screen television	Walk backwards
Around picnic table	Walk on knees
Away from monument	Walk
Up entrance stairs	Rocky run (run while punching the air)
Around palm tree	Ballet dance (spin with hands together over head)
To wall of building	Walk on all fours
Down hill	Scoot
To tree	Roll
Away from bush	Walk bowlegged
Into gazebo	Tiptoe
Past modern art statue	Stomp
Around park bench	Right-legged hop (hold left leg with left hand)
To drinking fountain	Run
Down playground equipment steps	Walk in slow motion
Down bleachers	Walk while making large arm circles
Up slide	Chicken dance
Up sloping sidewalk	Walk in very large steps
Out of garage	Sidestep
Experiment 4	
Into soccer net	Slide
Out of soccer net	Roll
Into gazebo	Ballet dance (dance on toes with hands above head)
Out of gazebo	Spin

(*Appendices continue*)

Appendix A (*continued*)

Extrinsic motions	Intrinsic motions
Experiment 4 *(continued)*	
To volleyball net	Run
Away from volleyball net	Walk in very large steps
Circle flower statue	Monkey walk
Past flower statue	Somersault
Out of tennis court	Hop
Into tennis court	Chicken dance
Away from lake	Combat crawl
To lake	Scoot
Up hill	Walk on knees
Down hill	Crab walk
Circle stop sign	Shuffle feet
Past stop sign	Robot walk
Away from water pipes	Fly like an airplane (run with hands to sides)
To water pipes	Jump
Circle statue	Tightrope walk
Past statue	Limp
Past traffic cone	Moonwalk
Circle traffic cone	Walk bowlegged
To car	Tiptoe
Away from car	Stomp
Circle emergency phone	Skip
Past emergency phone	Walk
Down stairs	Walk while flapping like a bird
Up stairs	Frankenstein walk
Out of pergola	Walk in slow motion
Into pergola	Swimming stroke
Past park bench	Crawl on hands and knees
Circle park bench	Lunges
To tree	Cartwheel
Away from tree	Leapfrog
Into building	March
Out of building	Dance

Appendix B

Fitting the Results of Experiments 3 and 4 to Yonelinas' (1999) Dual-Process Source Memory Model

Average ROC functions from each condition of Experiments 3 and 4 were fit using the formulas provided by Yonelinas (1999). The old–intrinsic conjunction and old–extrinsic conjunction discrimination conditions were fit by a model involving three free parameters: R_t, or the probability of recollecting having seen a target action performed by the same source (a.k.a., the target source) earlier; R_l, or the probability of recollecting having seen the target action performed by a different source (a.k.a., the lure source) earlier; and d', or the discriminability of the old and conjunction items on the basis of familiarity. Using these three parameters, the following formula, adapted from Yonelinas (1999), was used to fit each point on the ROC function:

$$p(\text{“yes”} \mid \text{old}) = p(\text{“yes”} \mid \text{conjunction}) + R_t + (1 - R_t)(\Phi[(d'/2) - c] - (1 - R_l)(\Phi[-(d'/2) - c])$$

In this formula, p(“yes”|old) refers to the probability of accepting an old item at or above the criterion level of confidence for a given point on the receiver operating characteristics (ROC) function, p(“yes”|conjunction) refers to the probability of accepting a conjunction item at the same level of confidence, R_t refers to the likelihood of recollecting having seen an old item previously (which would lead one to be more likely to accept the old items than to accept the conjunction items), and the remainder of the equation represents the condition in which an old item is not recollected $(1 - R_t)$, in which case the relative likelihood of accepting the old and conjunction items is influenced by the familiarity levels of those two item types. In this last part of the equation, $\Phi[(d'/2) - c]$ represents the probability that the familiarity level of an old item will exceed a response criterion (chosen separately for each point on the ROC function), whereas $\Phi[-(d'/2) - c]$ represents the probability that the familiarity level of a conjunction item will exceed the same crite-

(*Appendices continue*)

rion, assuming that the two distributions are normal and of equal variance, with d' representing the distance in z-score units between the means of the two distributions. The familiarity term for the conjunction items is multiplied by $(1 - R_l)$, representing the probability that participants will NOT recollect having seen the target action performed by a different actor earlier. Such recollection would mitigate the influences of familiarity on the likelihood of accepting the conjunction items, given that each action was only performed by a single actor, and thus if a participant recollected having seen a different actor perform this same action earlier, then the current actor could not have performed this action regardless of how familiar the conjunction item appears.

An exhaustive search was performed on the set of parameter values that best fit each ROC function, using the formula described above. For each set of parameter values, a unique criterion threshold c was chosen for each point on the ROC function that minimized the sum of the squared differences between the estimated and actual likelihoods of accepting both the old and conjunction items. The sum of the squared differences over both item types and over all five points on the ROC function was used as a measure of the fit of the set of parameter values. The best fitting sets of parameters are presented in Table 1.

ROC functions from the old–new extrinsic motion and old–new intrinsic motion discrimination conditions were also fit using the formula presented above, except that the R_l parameter was fixed at 0. This reflects the assumption that participants should not recollect having seen the action in a lure item performed by a different actor earlier, because all of the lure items in these conditions involved new actions that had not been performed by anybody earlier in the experiment. Performance in these conditions could thus be summarized in terms of two variables, R_t and d', reducing the dual-process source-memory model to a special case that Yonelinas (1999) terms the *standard recognition model*. Again, the best fitting set of these parameters for the two old–new discrimination conditions are presented in Table 1.

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