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The development of reasoning about the temporal and causal relations among past, present, and future events

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ABSTRACT

Children's capacity to reason about temporal and causal relations among past, present, and future events was investigated. In two studies, 4- and 6-year-olds ($N = 160$) received structurally analogous search and planning tasks that required retrospective or prospective temporal–causal reasoning, respectively. The search task was compared with a closely matched control task that did not require temporal–causal reasoning. Results revealed that (a) both age groups solved the control task, (b) 6-year-olds mastered both retrospective and prospective tasks, and (c) 4-year-olds showed limited competence in both retrospective and prospective tasks. The current study, thus, suggests that flexible temporal–causal reasoning develops in parallel for past- and future-directed reasoning, is qualitatively different from simpler forms of temporal cognition, and develops during the late preschool years.

Introduction

The ontogeny of temporal cognition has been the focus of much recent research in cognitive development. Most prominent, a growing body of work has focused on the capacity to mentally reexperience the past and to preexperience the future—often called "mental time travel" (MTT) (Atance, 2008;

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Suddendorf & Corballis, 1997, 2007). Theoretically, the basic idea behind research on mental time travel is that there is a unitary capacity to cognitively travel in time that underlies our thinking about both past and future events (Atance & O'Neill, 2001; Bischof-Köhler, 2000; Tulving, 1999, 2005). Empirically, MTT research suggests that the two capacities (to reason about the past and to reason about the future) emerge in synchrony and correlated fashion between 3 and 5 years of age (see Suddendorf & Redshaw, 2013, for a review). Joint emergence and systematic correlations between past and future cognition have been found, for example, in language understanding (yesterday/tomorrow) (Busby & Suddendorf, 2005; Harner, 1975) and tasks involving the concept of a past self (delayed self-recognition) and the concept of a future self (delay of gratification) (Lemmon & Moore, 2001). In addition, adult neuroscientific work suggests shared underlying neural substrates of episodic memory and episodic foresight (Addis, Wong, & Schacter, 2007; Klein, Loftus, & Kihlstrom, 2002). Converging evidence for fundamental cognitive changes at around 3 to 5 years of age comes from related lines of research on the development of temporal language (Friedman, 2004; Harner, 1980; Hudson, Shapiro, & Sosa, 1995), episodic memory (Gopnik & Graf, 1988; Nelson, 1993; Perner & Ruffman, 1995), and future planning (Atance & Jackson, 2009; Atance & O'Neill, 2005; Russell, Alexis, & Clayton, 2010; Thompson, Barresi, & Moore, 1997).

Less focus, however, has been put on the question of which *conceptual capacities* exactly underlie children's temporal cognition. Which aspects of time do children represent and in which ways? Our folk concept of time comprises a number of essential properties of temporal matters. At a minimum, time is conceived of as a sequence of events such that each event in time bears some temporal relations to the present (having happened *before* the past or going to happen *after* it). Relatedly, any two events in time stand in a definite temporal relation to each other and are linked by causal relations such that—asymmetrically—earlier events may causally have an impact on later events (but not vice versa) (Hoerl & McCormack, 2011; Kutach, 2011).

Mature thinking about time, thus, involves the appreciation of temporal–causal relations between events and the capacity to apply this explicit conceptual representation flexibly to past and future contexts. When we know that an effect, E, is usually brought about by a cause, C, and witness E taking place, we infer that C must have happened before. And when we plan for the future, we know that when we would like E to happen at a certain point in time, t_E, we would need to bring about C at some point in time before $t_{E.}$

This kind of explicit reasoning on the basis of temporal and causal information is sometimes called temporal–causal reasoning (TCR) (Hoerl & McCormack, 2011; McCormack & Hoerl, 2005). Crucially, this form of reasoning needs to be distinguished from simpler cognitive processes with which it might be confused such as merely understanding the temporal priority principle (causes precede effects) (e.g., Bullock & Gelman, 1979; Rankin & McCormack, 2013) or—most important—from processes that are sensitive to temporal–causal relations without explicitly representing them. One example of such simpler processes is children's capacity to keep track of the causal flow of events over time (without representing it explicitly) in varieties of invisible displacement object permanence tasks (Haake & Somerville, 1985; Piaget, 1954; Somerville & Capuani-Shumaker, 1984). In typical invisible displacement tasks, participants see an object, O, being occluded, say in the experimenter's fist, at time t_1. Then the fist moves into Box 1 at t_2, reappears at t_3, and moves into Box 2 at t_4 before the empty hand reappears from Box 2 at t_5. Crucially, at t_3 the experimenter opens his or her fist and—in different conditions—shows either that O is still there or that it is not there anymore before closing the fist again. The child's task is now to determine where O is. Arguably, this task can be solved in much simpler ways. Participants do not need to explicitly reason about temporal and causal relations. Rather, over time they can simply update their representation of the whereabouts of O based on the current perceptual information (in the one case, seeing directly that O got lost in Box 1 when the hand at t_3 is empty; in the other case, seeing the object at t_3 in the hand and then keeping track of the hand with the object and seeing directly at t_5 that the object got lost in Box 2 (see McColgan & McCormack, 2008).

In contrast to explicit temporal–causal reasoning, such updating is, however, limited in fundamental ways. Although TCR works flexibly into the past and future on the basis of information about the order of events and potential causal relations (in the past, present, or future), updating can be made use of only in the present in a given situation on the basis of perceptually available information.

This is analogous to the scopes and limits of different forms of spatial cognition. Implicit representations of spatial matters, such as the "homing vectors" used in insect navigation (e.g., Fujita, Loomis, Klatzky, & Golledge, 1990), might allow a participant to constantly keep track of how to get to a certain place (home) while moving around and in this sense represent the spatial relation of this place to the participant's current place implicitly. But that does not mean that this relation is coded in an explicit spatial representation that can be flexibly used in reasoning. For example, an explicit representation of the relation of "home" to one's current location, such as "Home is 15 miles north from here," allows one to reason flexibly about this relation in relation to other spatial matters, such as "Home is in the same direction as New York but closer." The implicit representations of homing vectors and the like, in contrast, merely allow the participant to act on those representations in circumscribed and inflexible ways (i.e., to get home).

Evidence for the development of flexible temporal–causal reasoning comes from recent studies by Povinelli, Landry, Theall, Clark, and Castille (1999) and McCormack and colleagues (McColgan & McCormack, 2008; McCormack & Hoerl, 2005, 2007). The basic logic of the tasks used in these studies is that participants needed to mentally reconstruct (or preconstruct) a sequence of causally linked events in order to correctly infer a present (or an anticipated future) state of the world (e.g., an object's location). Importantly, these tasks were designed in such a way that they required proper TCR because children could not perceptually update their representations of the location of the object in question. Instead, children needed to combine information about the temporal relations of some events with their knowledge of possible causal relations between the events. In one task designed to assess past-directed TCR, children learned that an action, A, produced the effect E_A, that another action, B, caused the effect E_B, and that the effect of one action was overridden and replaced by the effects of temporally successive actions. On the basis of information about the order of two successive events, only 5-year-olds were able to flexibly combine this information and infer the ultimate effect correctly (if A was before B, then E_B would hold in the end, but if B was before A, then E_A would hold in the end) (McCormack & Hoerl, 2005, 2007; see also Povinelli et al., 1999).

In a different study, McColgan and McCormack (2008) compared children's temporal–causal reasoning skills in both temporal directions using separate yet structurally analogous tasks for reasoning about the past and reasoning about the future. In a *search task*, children observed a puppet walking through a miniature zoo, passing different cages and taking a Polaroid picture at the kangaroo's cage. At the end of the visit, the puppet noticed the camera to be missing. In view of the photo of the kangaroo, children were asked to indicate where in the zoo the camera might have been lost. If children correctly combined knowledge about the temporal order of events (determined by the direction of the path) with causal evidence provided by the photo, then they would choose only locations that were visited *after* the kangaroo's cage. Both 4- and 5-year-olds, but not 3-year-olds, succeeded in this task.

Reasoning about the future was assessed in a similar *planning task*. Children were told that a puppet wanted to visit the zoo and take a picture of the kangaroo. Children's task was to preposition the camera in the zoo and enable the puppet to take the desired picture when passing by the kangaroo's cage. Again, children needed to combine spatiotemporal knowledge about the direction of the path with causal knowledge about the course of events ("picking up the camera" is a causal prerequisite for "taking a picture"). In a series of five experiments, 5-year-olds solved this task correctly by prepositioning the camera at a location *before* the kangaroo's cage, whereas 3- and 4-year-olds did not perform at an above-chance level (McColgan & McCormack, 2008).

In sum, these studies suggest that temporal–causal reasoning emerges at around 4 or 5 years of age and that there might be an asymmetry such that past-directed TCR precedes future-directed TCR. However, these studies leave open a number of important questions. First, existing tasks might have overestimated children's competence, producing false positives. This might have been the case because there was a fundamental confound between the type of task and the correct answer; in the search task the correct answer was always the location(s) *after* the kangaroo, whereas in the planning version it was always the location(s) *before* the kangaroo. Children's responses, therefore, might result from a bias to the particular side in the respective task. Results would be more convincing if children would also succeed in tasks where a future location *after* the kangaroo's cage needed to be inferred in the planning version and a location *before* the kangaroo's cage needed to be inferred in the search task, respectively. Second, in light of this confound between condition and correct answer, the asymmetry found between past- and future-directed TCR (the former preceding the latter) is difficult to interpret. The pattern of responses in the 4-year-olds (mastering only past-directed tasks) might have come from a default tendency to choose locations after the kangaroo's cage (resulting in correct answers in the past condition but incorrect answers in the future condition). Finally, the underlying assumptions of these studies are that (a) the tasks require TCR and cannot be solved by simpler processes such as mere updating and (b) very similar tasks that do not necessarily require TCR should be solved earlier in development. However, because these assumptions were not empirically tested in those studies, whether they are in fact true is a very interesting open empirical question[1].

The rationale of the current studies, therefore, was to systematically explore the early development of temporal–causal reasoning by following up on previous work and systematically testing for these open questions. To this end, the (a)symmetry of TCR about past and future events was investigated by systematically comparing the performance of children in structurally analogous search and planning tasks in which potential confounds between the conditions were removed. To directly distinguish TCR from simpler cognitive processes, in particular mere updating, a minimal contrast was devised between two versions of the past-directed search task that could or could not be solved by updating.

Both 4- and 6-year-old children were tested because previous studies have shown this to be the age where temporal–causal reasoning emerges and undergoes fundamental development (in contrast to McColgan & McCormack, we tested 6-year-olds rather than 5-year-olds because we expected our new, de-confounded tasks to be potentially more difficult and aimed at finding an age at which clear competence was already in place). Study 1 investigated past- and future-directed TCR in a future planning task and two structurally analogous search tasks (one of which required the structurally analogous TCR as the future planning task and the other of which could be solved much more simply by updating). Study 2 followed up on the findings of Study 1 by testing for potential factors that could explain why some of the search tasks in Study 1 were easier than others.

Study 1

Method

Participants

In total, 60 4-year-olds (48–60 months, mean age = 54 months, 30 boys) and 60 6-year-olds (72–83 months, mean age = 77 months, 30 boys) were tested. An additional 5 children were excluded from the final sample due to technical error (*n* = 1), uncooperative behavior (*n* = 2), or a delay in language development that hindered the child's understanding of the stimuli (*n* = 1). Children in both studies were native German speakers, came from a mixed socioeconomic background, and were tested either in a quiet room at their day-care centers or in the child lab facilities of the authors' home institution.

Design and procedure

In a between-participants design, children were tested in three conditions; the *prospective reasoning group* received a planning task, whereas the *retrospective reasoning group* and the *updating group* engaged in a search task. Each child received 4 trials (2 in which "Location 1" was the correct answer and 2 in which "Location 2" was the correct answer; see below). For each trial, children watched a video clip together with the experimenter (E) on a notebook computer. Depending on test group, E paused the video once or twice in order to make children verbally recapitulate what happened so far or to give certain hints (see below for details). At the end of each video, children saw a still image of the final scene and was asked to point toward a location in the scene's setup where an object must have been lost throughout the story (*search tasks*) or where an intervention should be performed in the future (*planning task*). For answering these questions, children were prompted to choose between two possible locations represented by two identical-looking landmarks in the scenario that were positioned on the left side (Obstacle 1) and on the right side (Obstacle 2) of the screen (see Fig. 1).

[1] See McCormack and Hoerl (2005) for such a minimal contrast pair of another temporal task that had two versions: a version that can be solved by mere updating and another version that requires TCR.

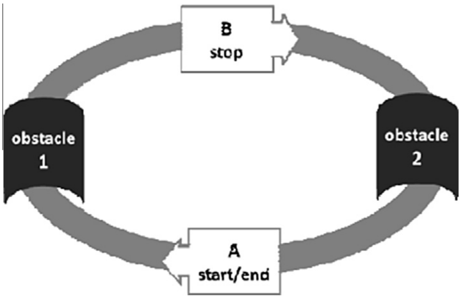


Fig. 1. Schematic model of the setup children saw on the screen. A = starting point in all video clips and ending point in search task (where loss of tool is recognized). B = destination for the delivery of objects or intended stopover for picking up objects (planning task with Target Location 2 only). Obstacles 1 and 2 = potential locations of a lost item (search task) or candidates for a future intervention (planning task). Obstacles 1 and 2 are identical with Target Locations 1 and 2.

All materials that appeared in the videos were small toy objects manipulated by the hands of an anonymous puppet player. Children listened to the narration of the story (voice off camera) while their attention toward the relevant elements on the screen was also supported by the puppet player's gestures.

Tasks. Irrespective of condition, children were presented with the same four scenarios of a character transporting goods in a container around a loop road (e.g., a girl walking on a loop road carrying a backpack, a train with wagons traveling on a circular track; see Appendix). The direction of the round trip was always clockwise, as indicated in Fig. 1. In all scenarios, the character and container passed two obstacles behind (or under) which they disappeared from observers' view for an instant (e.g., the girl passing through hedges that overgrew the way, the train passing two tunnels). In between the obstacles, there was a stopover where goods should be delivered or picked up.

In addition to counterbalancing the order of alternating target locations (i.e., beginning with target (location) = 1 or 2), also the presentation of scenarios within a session was varied systematically within test groups.

Planning. In a demonstration video at the beginning of each trial, children observed the character going on a circuit on the loop road. In the video, the narrator mentioned that sometimes the road could be very bumpy (and analogously for the other scenarios; see Appendix), so that goods could get lost. Then the character was introduced and shown to transport two objects around the loop track, losing one object at Obstacle 1 and the other at Obstacle 2[2]. A short verbal recapitulation together with E ensured that all children understood that goods had fallen out of the container when it passed both Obstacle 1 and Obstacle 2. Then children learned about the character's future goal, which varied depending on the task's target location. For example, a girl intended to bring a picture to her friend's house, which was located in between two hedges (transport object from A to B, target location = Obstacle 1; see Fig. 1). In trials where Obstacle 2 was the target location, the goal in this case was to return an object from B (e.g., from the friend's house) to the starting point A. To ensure that children remembered the basic structure of the event, E prompted them to recapitulate the goal, the path‘s direction, and the problem of losing goods at the obstacles, assisting them if necessary. Children were then presented with a

[2] The rationale for using this demo video was to establish the requisite background knowledge necessary to understand the task structure in the first place. Only when understanding when and how goods can get lost on the way will children be able to plan ahead and design interventions in order to avoid such losses. Such demo videos were not necessary in the retrospective searching conditions where children in a given test trial saw an event in the course of which objects got lost and needed to reconstruct where the loss had happened (see below). Thus, the retrospective reasoning test trials themselves introduced the background knowledge that was necessary to solve the task. Furthermore, children in the retrospective condition were not familiarized too much with the events in question, following recent methodological approaches by McColgan and McCormack (2008) and Suddendorf and Corballis (2010) that stress the importance of tapping spontaneous, uninstructed temporal reconstruction and preconstruction.

possible solution to that problem (e.g., a bridge was brought up and could be built over a hedge; see Appendix). After careful explanation of the possible solution, E pointed out to children that this intervention could be performed only once and at one single obstacle. E then repeated the character's goal, saying, for example, "The girl wants to bring the picture from here to there [pointing toward A and B on the screen]. But this time the picture should not get lost!" E asked the crucial test question: "What do you think—over which hedge do we need to build the bridge?" (see Table 1 for details). In all tasks, if a child did not give an answer spontaneously, E repeated these final sentences up to two times. Children never received feedback concerning the correctness of their answers.

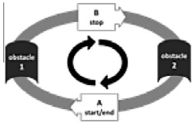
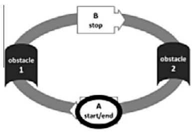
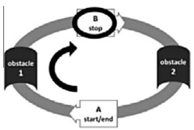
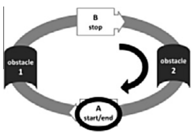
Searching. There were two analogous, closely matched versions of a search task. Children in the retrospective reasoning group were—after a short introduction to the scenario—immediately presented with the character's goal, which was the same for Target Locations 1 and 2, namely, bringing an object from A to B (see Fig. 1). But importantly, the character's goal consisted of two subgoals: (a) transporting the object to B and (b) performing a specific action with it (e.g., a girl wants to bring a picture to her friend's house in order to hang it up on an empty spot on the wall; see Appendix). Children observed the character's preparations for departure at the starting point, which always consisted of loading the object and an additional tool into the container (e.g., packing the picture into the girl's backpack and also a tape-roll in order to fix the picture on the friend's wall). Children then saw the character disappearing behind Obstacle 1, stopping at B, and unloading the container. The character's subsequent actions differed as a function of the availability of the tool. In Target Location 2 trials, the object and tool were used so that the goal was fully accomplished (e.g., the picture hangs on the wall, fixed with tape) and the tool was put back into the container. In contrast, in Target Location 1 trials, when opening the container, there was *only the object* left inside. In this case, only a subgoal (1) was accomplished (e.g., the picture was put on the ground, and the spot on the wall was left empty as it was before). The presence or absence of the tool at B was not commented on by the narrator, and E showed no reaction to the opening of the container. It was only after traveling back to A (by passing Obstacle 2) that the character realized the loss of the tool when finally unloading the container. The loss was emphasized in the last scene of the narration and directly linked to the test question, for example, "Look, the tape-roll is not there anymore! It must have fallen out of the backpack in one of the two hedges! What do you think—in which hedge did she lose the tape-roll?" After the video had stopped with a still image of the last scene, E looked at the children, waiting for them to give an answer to the test question. Note that in this task, to answer the test question correctly, children needed to remember whether the tool had been present at B or not. This information was retrospectively available through the causal cue at B (the still image still showed whether the goal had been fully or only partially accomplished).

The task for the updating group was different in this respect, although the very same video material was used. The difference resulted from three modifications that enabled children to track the relevant item (i.e., the tool) throughout the video. First, children tested in this group received an additional demonstration video at the beginning of each trial; this video was similar to the one used in the planning task (see description above), but in this group it served the purpose of accustoming children to the object search context. Second, before the character's departure at A, children were prompted by the narrator and by E to focus their attention on the tool's whereabouts (e.g., narrator: "Now pay attention to what is going to happen to the tape-roll!"; E: "Okay, what are we supposed to pay attention to?"). Third, when unloading at B, E summoned children's attention in order to encourage a mental update of the tool's location ("Look what's inside!").

Results

Data points from 2 4-year-olds were excluded from the final analysis (1 from the retrospective condition and 1 from the prospective condition) because they failed to give unambiguous answers despite repeated questioning (choosing either both obstacles or none). Because preliminary analyses revealed no differences in performance across trials or between the different scenarios, sum scores were computed for the mean number of trials with Obstacle 1 answers (0–2) versus those with Obstacle 2 answers (0–2) a function of condition and age group. These values can be seen in Fig. 2.

Table 1
Structure of planning and search task in Studies 1 and 2.

Movement and position of container per scene	Scene	Planning task (Study 1)		Search task (Study 1)				Search task (Study 2)	
		Prospective reasoning condition		Retrospective reasoning condition		Updating condition		Retrospective reasoning condition	
	Demo-clip	Cargo gets lost at Obstacles 1 and 2				Cargo gets lost at Obstacles 1 and 2			
		Target Location 1: Container is loaded with object (visible)	Target Location 2: Container is empty, object waits at B (visible)						
	Goal and instruction	→Transport object from A to B	→Transport object from A to B	Container is loaded with object and tool Transport object from A to B, use tool at B				Container loaded with object only Transport object from A to B, tool would be useful at B	
		"Intervention at one obstacle will prevent loss of goods at this obstacle"				Hint: "Pay attention to the tool!"			
						Hint (opening container at B): "Look what's inside!"			
	Production of causal cue			Target Location 1: tool absent →no tool use	Target Location 2: tool present → tool use	Target Location 1: tool absent → no tool use	Target Location 2: tool present → tool use	Target Location 1: tool present → tool use	Target Location 2: tool absent → no tool use
	Test question	"At which obstacle do we need to perform the intervention?"		Tool is missing - "At which obstacle did s/he lose the tool?"				Tool is discovered - "At which obstacle did s/he find the tool?"	

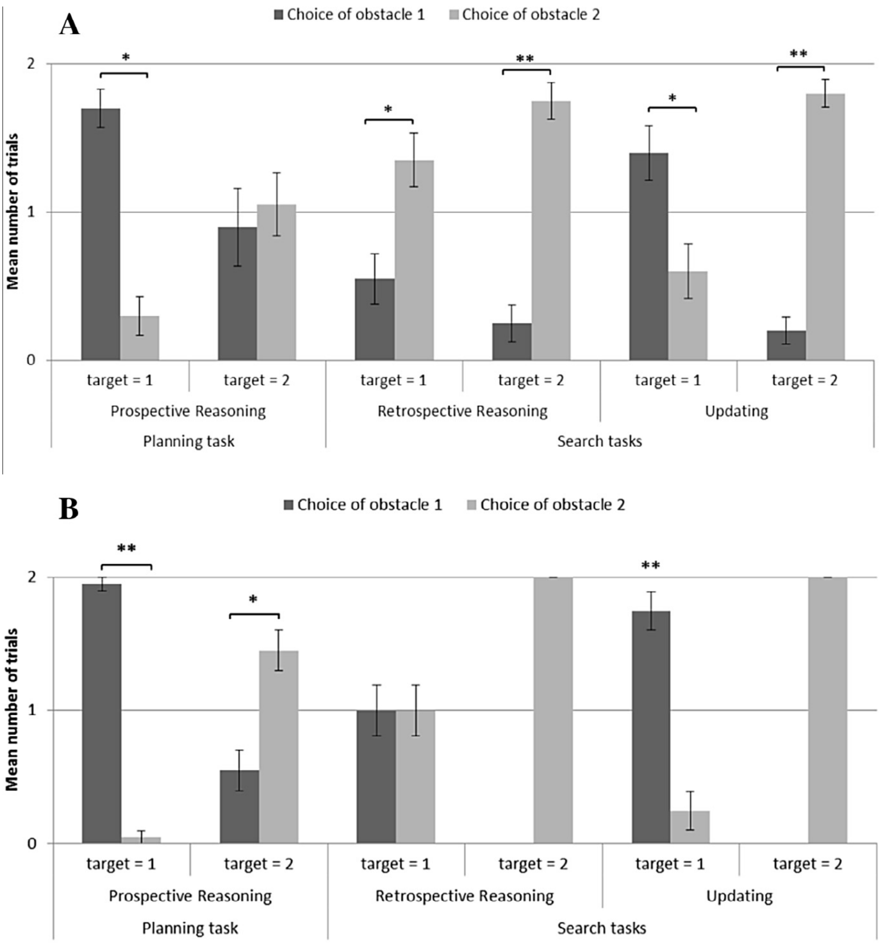


Fig. 2. Mean numbers of trials with choice of Obstacle 1 and Obstacle 2 as a function of condition and target location for 4-year-olds (A) and 6-year-olds (B) in Study 1 (significance levels: $^{*}p < .05$; $^{**}p < .01$).

For purposes of statistical comparisons across age groups and conditions, in each condition a difference score was computed of Obstacle 1 minus Obstacle 2 answers (ranging from -2 to 2). A difference score of 2 would be the normatively correct pattern in *target = 1* versions, whereas a score of -2 would be the normatively correct pattern in *target = 2* versions. A 2 (Target Location: 1 or 2) $\times$ 3 (Condition: retrospective, updating, or planning) $\times$ 2 (Age Group) mixed-factor analysis of variance (ANOVA) on this difference score yielded significant main effects of condition, $F(2, 114) = 39.57$, $p < .001$, $\eta^2_p = .41$, and target location, $F(1, 114) = 164.59$, $p < .001$, $\eta^2_p = .59$. There was a significant interaction of target location and age, $F(1, 114) = 13.54$, $p < .001$, $\eta^2_p = .11$, and also an interaction of target location and condition, $F(2, 114) = 7.60$, $p = .001$, $\eta^2_p = .12$. Follow-up pairwise comparisons of the difference scores between the age groups revealed significant differences in the retrospective target = 2 and in the updating target = 2 conditions, $t(38) = 2.03$, $p < .05$, $d = 0.64$, and $t(38) = 2.18$, $p < .05$, $d = 0.69$, respectively, and a trend for the prospective target = 1 condition, $t(38) = 1.82$, $p < .08$, $d = 0.58$.

To test for children's competence in each of the conditions and each of the age groups, separate *t*-tests were performed for both age groups, testing the difference between trials with Obstacle 1 answers (0–2) and those with Obstacle 2 answers (0–2). The 4-year-olds in the updating conditions performed above chance both in target = 1 trials, $t(19) = 2.18$, $p < .05$, $d = 0.49$ (answering Obstacle 1 more often than Obstacle 2) and in target = 2 trials, $t(19) = -8.72$, $p < .001$, $d = 2.00$ (showing the reverse pattern). In the retrospective reasoning group, they performed above chance only in target = 2 trials, $t(19) = -6.10$, $p < .001$, $d = 1.40$. In trials with target = 1, children in this group gave significantly more incorrect Obstacle 2 answers than correct Obstacle 1 answers, $t(19) = -2.379$, $p < .05$, $d = 0.53$. In the prospective reasoning group, 4-year-olds showed no preference for one of the obstacles in trials with Target Location 2 ($p = .82$) but performed above chance in trials with Target Location 1, $t(19) = 5.48$, $p < .001$, $d = 1.20$.

Like 4-year-olds, 6-year-olds succeeded in both versions of the updating task, actually performing very close to ceiling (target = 1: $t(19) = 5.25$, $p < .001$, $d = 1.20$; for target = 2, performance was perfect and so no inference statistics could be computed). In contrast to the 4-year-olds, the older children succeeded in both conditions of the planning task (target = 1: $t(19) = 19.00$, $p < .001$, $d = 4.30$; target = 2: $t(19) = -2.93$, $p < .01$, $d = 0.66$. In the retrospective conditions, 6-year-olds performed perfect in target = 2 trials (all children chose Obstacle 2 in both trials), but performance did not differ from chance in the target = 1 version ($p = 1.00$).

Discussion

The current study tested 4- and 6-year-olds on structurally analogous retrospective searching and prospective planning tasks. The retrospective task was compared in a minimal contrast with an updating task that was supposed to be solvable without temporal–causal reasoning. The results revealed, first, that the updating task was the easiest and was mastered in all versions by both age groups. Second, the superficially very similar retrospective search task was indeed more difficult and was not fully mastered in all versions by either of the two age groups. Both 4- and 6-year-olds succeeded in target (location) = 2 versions but failed in target = 1 versions (6-year-olds answering at chance and 4-year-olds even significantly below chance). Third, the structurally analogous prospective planning task was fully mastered by 6-year-olds, who answered correctly in all versions, and was only partly mastered by 4-year-olds, who answered correctly in target = 1 versions but not in target = 2 versions.

How are these negative findings to be interpreted, in particular regarding the failure of both age groups in the target = 1 versions of the retrospective condition? Do these findings suggest true competence problems, or might they be indicative of some performance problems due to extraneous task demands? One possibility along the latter lines is that children's competence got masked by the use of a temporal–spatial primacy bias. It is conceivable that when engaged in temporal–causal reasoning, children travel along the time line, so to speak, either backward or forward in time. When doing so, they then often settle on the first possible answer they encounter. This would lead to the following pattern. In the retrospective reasoning task, they travel backward in time (and therefore space), first encountering Location 2 and settling on this answer. In prospective reasoning, in contrast, children travel forward in time (and therefore space), first encounter Location 1, and settle on this answer. Such a strategy (mentally starting to travel from Location A and then settling on the first potential answer) might have been particularly salient in the prospective reasoning condition because in the demo videos of this condition the protagonist always started from Location A.

Alternatively, another way in which Study 1 might have posed performance problems that masked children's competence is that there were asymmetric demands in terms of reasoning processes involved in different conditions. In the prospective reasoning tasks, there is an asymmetry between conditions in terms of reality-based reasoning versus hypothetical reasoning. In target = 1 conditions, the vehicle is at Location A and the question is how it can safely travel and transport something from there to B; that is, one can reason from the current state of affairs. In target = 2 conditions, in contrast, the vehicle is at Location A but the question is how it can safely travel and transport something from B to A—which means that one needs to reason from the future hypothetical situation in which the vehicle is already at B.

Relatedly, in the different retrospective reasoning conditions, there are asymmetries in terms of evidential relations and the resulting demands on counterfactual reasoning. In target = 2 versions of the retrospective conditions, there is positive evidence (still visible at the time of the test question, e.g., in the form of the tape that fixes the picture on the wall) that the object was still present at B, from which the participant can infer that it must have been lost at Location 2 (along the following lines: "The picture is on the wall, fixed with tape. Thus, the tape was still present at B. Therefore, it must have been lost at Location 2"). In target = 1 versions, in contrast, there is no such positive evidence, only absence of evidence that the object was still present at B (embodied in the fact that the picture lies on the ground rather than hanging on the wall). Consequently, the line of reasoning required in order to infer the object's location seems to be much more complicated: "If the tape had been present at B, then the picture would have been fixed on the wall. Because the picture lies on the ground, the tape must have been lost before B, so it must be in Location 1." This chain of reasoning seems to be generally more complex and, more specifically, requires rather sophisticated counterfactual reasoning—which is known to show protracted development from 4 years of age, sometimes even until 12 years of age, in tasks where children are explicitly and directly encouraged to make counterfactual inferences (Perner & Rafetseder, 2011; Rafetseder, Schwitalla, & Perner, 2013). In light of this complexity of counterfactual inferences, and in particular given that such inferences needed to be made spontaneously in the our task, it is possible that in the current study children failed to solve the Target Location 1 condition not because of constraints in their ability to reason about temporal–causal relationships but rather because of the task demands, in particular in terms of counterfactual reasoning.

Whereas in the prospective conditions it seems to be difficult, if not impossible, to tease apart the temporal–spatial primacy bias from the differential demands in terms of hypothetical reasoning, in the retrospective conditions the different potential factors (temporal–spatial primacy bias or differential demands in terms of evidential structure and counterfactual reasoning) can be straightforwardly experimentally disentangled.

Study 2

Study 2 followed up on the possible problem of differential task demands in the retrospective conditions of Study 1. Children were tested on a new version of the search task with reversed evidential structure. This time-conclusive (visible) evidence was provided for the identification of Obstacle 1 as target location, whereas evidence was negative in the case of Obstacle 2 being the target location.

Method

Participants

A different sample of 20 4-year-olds (49–59 months, mean age = 54 months, 11 boys) and 20 6-year-olds (72–83 months, mean age = 76 months, 8 boys), all native German speakers, was drawn from the same database as in Study 1. An additional 2 children were excluded from the final sample due to experimenter errors and problems in understanding the video stimuli.

Design and procedure

Children received four trials of the new search task with the same storylines, materials, and setup as in Study 1 except for one crucial change to the plot: Instead of *losing* the tool, in this new task the character would *find* the tool in either Obstacle 1 or Obstacle 2. This change became manifest in the course of events, first, when the character departed at A with the *object only* in the container (e.g., the picture). Second, in this new version, the tool could not be presented when explaining the character's goal, but instead E asked children what kind of tool would be useful in order to fully accomplish the stated goal (e.g., "Look, she wants to hang the picture up there on the wall. What do you think—what would one need in order to hang it up there?"). This was done to establish the connection between tool use and full achievement of the goal. If children did not name it spontaneously, E prompted the tool immediately (e.g., "I think a piece of tape would do (as well), right?"), and both agreed on this one as suitable for the goal's achievement. Third, the container was unloaded at B just as in Study 1, but this time in trials with target (location) = 1, tool and object were inside, whereas in target = 2 trials there was only the object. The action was performed accordingly with or without tool use, resulting in a visible causal cue at B in the former condition and a negative cue in the latter condition (e.g., target = 1: picture hangs on the wall fixed with tape; target = 2: picture leans on the ground). As in

Study 1, the presence or absence of the tool at B was not commented on by the narrator, and E showed no reaction to the opening of the container. It was only when returning to A and when the container was finally unloaded that the presence of the tool was emphasized (puppet player pointing toward the tool: "Look! On her way Lisa found a tape-roll! She must have found it in one of the two hedges!"). Test questions followed the very same structure of those in Study 1, for example, "What do you think—in which hedge did she find the tape-roll?"

Results and discussion

Because preliminary analyses revealed no differences in performance across trials or between the different scenarios, sum scores were computed for the mean number of trials with Obstacle 1 answers (0–2) versus those with Obstacle 2 answers (0–2) as a function of condition and age group. These values can be seen in Fig. 3.

For purposes of statistical comparisons across age groups and conditions, in each condition a difference score was computed of Obstacle 1 answers minus Obstacle 2 answers (ranging from –2 to 2). A difference score of 2 would be the normatively correct pattern in target = 1 versions, whereas a score of −2 would be the normatively correct pattern in target = 2 versions. A 2 (Target Location: 1 or 2) × 2 (Age Group) mixed-factor ANOVA on this difference score yielded a significant main effect of target location, $F(1, 38) = 63.33$, $p < .001$, $\eta_p^2 = .63$, and a significant interaction effect of target location and age group, $F(1, 38) = 15.83$, $p < .001$, $\eta_p^2 = .29$. Follow-up pairwise comparisons of the difference scores between the age groups revealed significant differences in both the target = 1 and target = 2 conditions, $t(38) = 2.92$, $p < .01$, $d = 0.93$, and $t(38) = 2.08$, $p < .05$, $d = 0.66$, respectively.

To test for children's competence in each of the conditions and each of the age groups, separate *t*-tests were performed for both age groups, testing the difference between trials with Obstacle 1 answers (0–2) and those with Obstacle 2 answers (0–2). As in Study 1, the 6-year-olds performed at ceiling in the new target = 2 trials, $t(19) = -8.72$, $p < .001$, $d = 2.00$. But in contrast to Study 1, they now answered the new target = 1 condition correctly, $t(19) = 5.48$, $p < .001$, $d = 1.20$. The 4-year-olds, as in Study 1, performed above chance in only one version of the task. In spite of the new evidential structure, this was again the Target Location 2 version, $t(19) = -2.37$, $p < .05$, $d = 0.53$. Performance in the target = 1 condition did not differ from chance performance, $t(19) = 0.62$, $p > .05$.

To test whether the crucial modifications introduced in Study 2 in the form of reversed evidential structure made a difference to children's answer patterns, separate follow-up comparisons of performance in each condition across studies were conducted. The 6-year-olds performed better in Study 2 than in Study 1 in both the target = 1 condition, $t(38) = -3.04$, $p < .01$, $d = 0.96$, and the target = 2

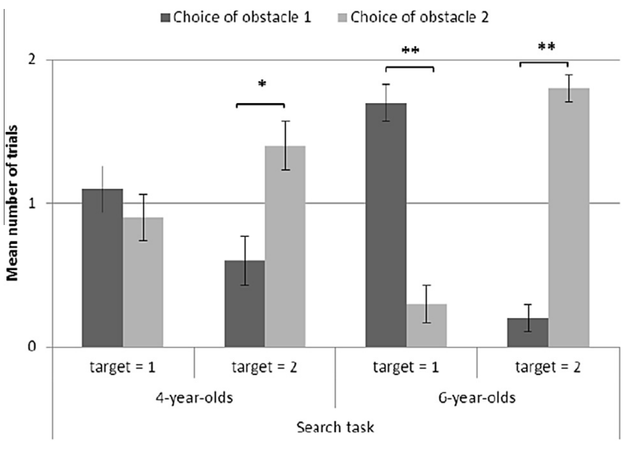


Fig. 3. Mean numbers of trials with choice of Obstacle 1 and Obstacle 2 as a function of age and condition in the search task in Study 2 (significance levels: $^{*}p < .05$; $^{**}p < .01$).

condition, $t(38) = -2.18$, $p < .05$, $d = 0.69$. The 4-year-olds did not perform significantly better in Study 2 compared with Study 1 in the target = 2 condition, $t(38) = -1.68$. $p > .05$. But performance improved significantly from Study 1 to Study 2 in the target = 1 condition, $t(38) = -2.15$, $p < .05$, $d = 0.68$—from below-chance performance in Study 1 to at-chance performance in Study 2.

These results suggests that 6-year-olds have solid competence to reason flexibly about temporal causal relations between past and present events but that this competence was masked in some versions of Study 1 by the specific task structure. In particular, it seems that the asymmetry of the evidential structure of the different versions of the retrospective tasks played a crucial role in Study 1; whereas children failed the Target Location 1 version in Study 1, when there was only indirect evidence for what the correct answer was, they easily solved the adapted Target Location 1 version in Study 2, which with a reversed evidential structure now involved positive evidence for the correct answer.

However, this interpretation leaves open two questions. First, why did the 6-year-olds in Study 2 now solve both versions of the task (Location 1 with direct positive evidence and Location 2 with only indirect evidence), whereas the 6-year-olds in Study 1 solved only the version with the direct positive evidence (Location 2)? Second, why did the 4-year-olds improve from Study 1 to Study 2 in the Target Location 1 version, moving from below-chance to chance performance, but still failed in Study 2? Quite clearly, what these findings suggest is that additional task demands were at play. In particular, the Target Location 1 versions of the task in both studies pose some additional demands (beyond evidential structure) that the Target Location 2 versions do not pose to the same degree. What could these additional demands be? One possibility is that they could have to do with temporal–spatial distance; when mentally reconstructing the course of events, one might take different directions in retrospection (backward) and prospection (forward) in mentally traveling along the track and thus hit on different locations first (Location 1 in prospection and Location 2 in retrospection) that become more salient as answers—resulting in what could be called a temporal–spatial proximity bias (see below).

General discussion

The current study investigated the early development of temporal–causal reasoning—the capacity to reason flexibly about the temporal and causal relations of past, present, and future events in the service of retrospection and prospection. Building on previous work, we pursued the following open questions. First, when does the capacity to engage in TCR emerge ontogenetically, and how robust and systematic is it from early on? Second, are past-directed TCR and future-directed TCR based on the same capacity and, therefore, emerge and develop together? Third, is TCR a qualitatively different capacity than simpler forms of keeping track of temporal matters? To address these questions, 4- and 6-year-olds were tested in analogous retrospective and prospective TCR tasks. Following up on earlier research, retrospective and prospective versions were closely structurally matched, extraneous factors were systematically controlled, and the retrospective task was compared with a closely matched, structurally similar task that differed in the crucial respect that it did not require TCR.

The results suggest, first, that the capacity for TCR emerges by 4 years of age in some form but undergoes important subsequent development until 6 years of age, where fully fledged competence about the past (Study 2) and about the future (Study 1) was found. Second, the findings speak in favor of the view that past-directed TCR and future-directed TCR are based on the same capacity by showing clear developmental symmetry of retrospective and prospective reasoning; the 4-year-olds showed analogous competence and limitations in past- and future-directed versions of the task, and the 6-year-olds showed the same robust competence—under suitable conditions—in both temporal directions. Third, findings from both age groups provide clear evidence that TCR is a qualitatively different, more complex form of temporal cognition than other forms of tracking temporal matters, in particular temporal updating; the 4-year-olds found structurally matched past-directed tasks that could be solved by mere updating to be much easier than the analogous search tasks that did require TCR.

These results replicate previous findings on children's developing competence in temporal–causal reasoning and extend them in important ways (McColgan & McCormack, 2008; McCormack & Hanley, 2011). In line with earlier research, conclusive evidence for full-blown TCR was found toward the end of the preschool years at around 5 or 6 years of age. In contrast to previous work, however, no evidence for an asymmetry between past- and future-directed TCR was found. And with a more stringent methodology controlling for potential confounding factors, the current work showed a less clear and more fragile pattern of competence in the 4-year-olds who managed to solve only one version of the search task (in which Location 2 was the correct answer) and only the complementary version of the planning task (with Location 1 as the correct answer).

So, how is this more fragmented pattern of performance in the younger children in the search and planning tasks to be interpreted? The results of Studies 1 and 2 together suggest that at least two factors might underlie the limitations in the younger children's performance. First, at least for the past-directed search tasks, the evidential structure seems to matter. The conditions of the search tasks mastered in Study 1 were exactly those in which there was direct positive evidence for the correct answer to the test question. This test question was where some object had been lost and children had direct positive evidence that the object must have been used in between Location 1 and Location 2 because it left a definite visible causal trace, and from this trace children could infer that the object had been present after Location 1 and, thus, must have been lost at Location 2. The other condition, in which Location 1 was the correct answer, required more complex reconstruction of the correct answer; from the fact that there was no visible causal trace of the object in between Location 1 and Location 2, together with the counterfactual premise that there would have been such a trace if the object had been present there, children needed to infer that the object must have been already lost at Location 1. The conditions in Study 2, therefore, were exactly reversed by implementing stories in which objects were found rather than lost; now there was direct, visible positive evidence that an object must have been found at Location 1 in one condition and a more indirect reconstruction from the absence of such evidence that the object must have been found at Location 2 in the other condition. With this reversed structure, 4-year-olds now still performed competently in the Location 2 condition and performed significantly better than in Study 1 in the Location 1 condition. The evidential structure, thus, made a difference.

However, it was far from making the whole difference because although children performed better, they still did not perform above chance in the Location 1 condition in Study 2. A second factor that seems to underlie the limited performance of 4-year-olds, thus, might be a general bias toward locations that are closer to one's starting point when mentally traveling through time. Children might have been subject to a spatial–temporal proximity bias such that in the direction that one mentally travels along the path (backward in retrospective tasks and forward in prospective tasks), the first location encountered becomes more salient and more difficult to mentally disengage from. The spatial–temporal proximity bias, thus, might be based to a large degree on demands in terms of inhibition and other forms of executive function known to undergo protracted developmental changes until middle childhood and beyond. Empirically, future studies should investigate the relation of such biases to measures of executive function.

On a more theoretical level, findings from such performance limitations, in particular in the younger children, are difficult to interpret and remain in need of theoretical clarification. Such a pattern of limited performance as was found in the 4-year-olds allows two broad classes of interpretation. One possibility is that the findings do reveal early competence that is masked by performance factors only in some conditions—the ones with complex inferential structure and the ones where cognitive biases get in the way of general competence. This would be analogous to one interpretation of heuristics and biases in judgment and decision making according to which reasoning biases are conceptualized as showing not that adults cannot reason rationally but only that their competence is often overridden by the works of such biases (e.g., Cohen, 1981; Stanovich & West, 2003; Stein, 1996). With regard to previous findings of competence in 4-year-olds (at least in past-directed tasks), this would mean that the current findings would basically replicate these findings and extend them by showing some accidental performance limitations. Alternatively, however, the fragile pattern of performance might be taken as indicative of fragile competence itself. The fact that the younger children showed performance only under limited conditions, this interpretation goes, implies the very lack of a flexible and general capacity to reason about temporal–causal relations. This would be analogous to another interpretation of heuristics and biases according to which the extant use of such heuristics and biases shows that humans do not reason rationally in the first place (e.g., Stich, 1990). With regard to previous findings of competence in 4-year-olds (at least in past-directed tasks), this would mean that the current findings fail to replicate and actually contradict them. It is a challenging open question for future research to systematically explore which of these two interpretations is correct. Like in the debate about the implication of reasoning biases for theories of human rationality, this might require the development of new experimental designs—in the current cases, designs that allow testing for the generality and flexibility of temporal–causal reasoning under conditions that lend themselves to the application of the biases in question to varying degrees.

A broader question for future research, finally, concerns the cognitive and developmental relations of temporal–causal reasoning as investigated here to other forms of temporal cognition. The current studies suggest that TCR emerges by 4 years of age and develops until the end of the preschool years. Other lines of research on children's temporal cognition have documented similar developmental changes in other aspects of experiencing and representing time; work on mental time travel suggests that beginning at around 4 years of age, children acquire analogous competence in both episodic memory and episodic foresight to act on past experiences and plan competently for the future (Suddendorf, Nielsen, & von Gehlen, 2011; Suddendorf & Redshaw, 2013). Work on the development of temporal language suggests that at around the same time, children begin to give verbal reports about their past and possible future experiences (Friedman, 2004; Hayne, Gross, McNamee, Fitzgibbon, & Tustin, 2011) and they begin to mentally decenter from their subjective present when asked about another person's thoughts at a different point in time (Cromer, 1971). Conceptually, there is much overlap of TCR with these capacities. TCR and MTT, for example, both describe capacities of flexibly representing the relation of the present to past or future events—capacities that contrast with simpler forms of time-tracking processes and that are taken to underlie both past- and future-directed thought in symmetrical ways. TCR, however, goes beyond MTT in that, apart from merely representing the relation between a past (or future) episode and the present, it also entails representations of temporal and causal relations between other episodes—in the past or in the future—that are used to make systematic and flexible inferences about past or future happenings. TCR and temporal decentering both involve the capacity to represent and coordinate more than two points in time (see McCormack & Hoerl, 2008)—again with the difference that TCR goes beyond merely representing temporal relations between events by including reasoning about and from temporal–causal relations. Despite this massive conceptual overlap, little research so far has systematically investigated the development of these different capacities in relation to each other. One of the fundamental challenges for future research on the development of temporal cognition, therefore, will be to systematically explore the empirical relations of these different forms and aspects of representing time in development.

Appendix A.

List of scenarios.

Scenario	Path	Rail	Sea	Sky
	A girl, Lisa, travels with pictures in her backpack on a loop road between her home (A) and her friend's house (B)	A train loaded with carrot(s) goes on a circular track between a station (A) and a rabbits hutch (B)	A captain's boat sails in a circle around rocks, transporting birdhouse(s) between harbor (A) and a bird's island (B)	A hot-air balloon goes on a circular flight route to transport light bulbs between a station (A) and a lighthouse (B)
Obstacles on the way (before and after B)	Two hedges overgrow the way	Two tunnels with bumpy tracks inside	Two rocks surrounded by driftwood	Two clouds cause turbulences

(continued on next page)

Appendix A. (*continued*)

Scenario		Path	Rail	Sea	Sky
Storyline: Planning (demonstration video and resume of verbal recapitulation with E)		Lisa puts two pictures into her backpack and walks over to B by crawling through a hedge. At B, it is discovered that she lost one picture in the hedge. On her way back home, she loses the second picture in the other hedge; back at A, there are no pictures left in her backpack. Things can get lost when Lisa crawls through the hedges	The train has two carrots in its wagon when passing the first tunnel. At B, it is discovered that one carrot fell off the wagon due to bumpy tracks inside the tunnel. Passing the second tunnel, the other carrot gets lost; back at A, there is no carrot left in the wagon. Things can fall off the train when it passes the bumpy tracks in tunnels	The captain has two birdhouses loaded in his boat. At B, it is discovered that he had lost one when sailing through the driftwood next to a rock. On his way back around the other rock, he loses the second birdhouse; back at A, his boat is empty. Things can fall off the boat when it sails through driftwood	Two light bulbs are inside the balloon's basket when it passes the first of two clouds. Landing at B, it turns out that one light bulb got lost because of the turbulence in the cloud. The second light bulb falls off the basket in another cloud; back at A, nothing is left in the basket. Things can get lost when the balloon passes clouds
Future goal	Target (location) = 1 transport object from A to B	Lisa discovers a third picture. She wants to bring it to her friend's house	Another carrot needs to be delivered in order to feed the rabbits	The captain wants to bring a new birdhouse to the bird's island	Another light bulb is needed at the lighthouse
	Target (location) = 2 transport object from B to A	Lisa wants to pass by her friend's house in order to pick up and take home one of her friend's pictures	Rotten carrot pieces need to be returned from the hutch to the train station	The captain intends to return an old birdhouse to the harbor in order to restore it	A broken bulb needs to be withdrawn from the lighthouse and taken in
Solution to prevent future loss of object		A bridge—built over one of the hedges	A new track—exchanging the bumpy one in one of the tunnels	A fishing net—traps the driftwood behind one rock	An air-screw—blows away one cloud
Storyline: Searching		Lisa wants to bring a picture to her friend Jule	The train brings a carrot to feed the rabbits	The captain delivers a birdhouse to the bird's island	The hot-air balloon delivers a new light bulb to the lighthouse
Subgoal requiring use of a tool		She wants to hang the picture on an empty spot of the friend's house's wall	The carrot needs to be chopped into smaller pieces	He wants to put the birdhouse high into the bird's tree	Dirt on the glass pane in front of the light needs to be removed

Appendix A. (*continued*)

Scenario		Path	Rail	Sea	Sky
Goods loaded at A (start)		She puts into her backpack: picture tape roll (tool)	The wagon is loaded with: carrot knife (tool)	He loads into his boat: birdhouse ladder (tool)	Balloon's basket is loaded with: light bulb cleaning cloth (tool)
Action at B	Target (location) = 1 (tool lost before B)	She leans the picture to the wall on the ground	The carrot is grossly tarred by hand	He puts the birdhouse on the ground next to the tree	The new light bulb is installed. It gleams through the dirty glass pane
	Target (location) = 2 (tool lost after B)	She uses the tape to fix the picture on the wall	The knife is used to chop the carrot into small pieces	He climbs up the ladder and puts the birdhouse high into the tree	The new bulb is installed and the glass pane cleaned with the cloth (light shines bright)

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