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The online processing of *only if* and *even if* conditional statements: Implications for mental models

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A sentential connective like *only if* or *even if* merges two simple propositions into a complex statement. This study used a visual world paradigm experiment to explore how this merging process proceeds online. We first presented participants with a short animation, illustrating different simple propositions that are possible to be merged by the sentential connectives. We then auditorily played an *only if* or an *even if* statement and recorded participants' eye movements on the concurrent test image. We observed that hearing the sentential connective results in more fixations on the tokens of the appropriate propositions that are eligible to be merged by the sentential connective. Each sentential connective elicited anticipatory effect suggests that once they heard the sentential connective, participants knew which propositions could be merged. We then discussed the implications of our results to the mental model theory of conditionals and the experimental studies reported in literature.

Keywords: Conditionals; *Even if*; Mental models; *Only if*; Visual world paradigm.

Sentential connectives like *and, if, even if, only if* in English are linguistic tools used to merge simple propositions into complex statements. By merging the same two simple propositions like (1a and 1b) with different sentential connectives, we deduce different complex propositions, like (2a–c).

(1) Simple propositions
  (a) *Astroboy helped the camel.*
  (b) *Astroboy got a hamburger as a reward.*
(2) Complex statements
  (a) *Once, Astroboy helped the camel; and he got a hamburger as a reward.*
  (b) *Only if Astroboy helped the camel, he got a hamburger as a reward.*
  (c) *Even if Astroboy helped the camel, he got a hamburger as a reward.*

Hypotheses (Johnson-Laird, 1983, 2005, 2010; Johnson-Laird & Byrne, 2002) have been proposed to explain how a sentential connective merges two simple propositions into a complex statement. Experiments (Egan, García-Madruga, & Byrne, 2009; Johnson-Laird & Byrne, 1989; McCloy & Byrne, 2002; Moreno-Ríos, García-Madruga, & Byrne, 2008; Santamaría & Espino, 2002;

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Santamaría, Espino, & Byrne, 2005) have also been reported in literature to test these hypotheses. Nevertheless, it remains unclear how this merging process unfolds online. To tackle this problem, we compared the online processing of complex statements like (2a–c) using the visual world paradigm of the eye-tracking technique (Cooper, 1974; Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995).

Complex statements like (2a–c) differ both in the contents and/or in the number of meaning components (Byrne, 2005) they express. A statement φ *and* ψ like (2a; repeated as 3) has only one meaning component φ ψ like (3a). A statement *only if* φ ψ like (2b; repeated as 4) has two meaning components: φ ψ like (4a) and *not-* φ *not-* ψ like (4b). A statement *even if* φ ψ like (2c; repeated as 5) has two different meaning components: φ ψ like (5a) and *not-* φ ψ like (5b).

(3) *Once, Astroboy helped the camel; and he got a hamburger as a reward.*
  (a) *Astroboy helped the camel. He got a hamburger as a reward.*
(4) *Only if Astroboy helped the camel, he got a hamburger as a reward.*
  (a) *Astroboy helped the camel. He got a hamburger as a reward.*
  (b) *Astroboy didn't help the camel. He didn't get a hamburger as a reward.*
(5) *Even if Astroboy helped the camel, he got a hamburger as a reward.*
  (a) *Astroboy helped the camel. He got a hamburger as a reward.*
  (b) *Astroboy didn't help the camel. He got a hamburger as a reward.*

To assess this analysis, we recorded participants' eye movements on a concurrent image when they were listening to complex statements like (3–5). This so-called visual world paradigm using the technique of eye-tracking (Cooper, 1974; Tanenhaus et al., 1995) has revealed two phenomena in the literature: First, participants tend to fixate more on the mentioned object in the concurrent image than on the unmentioned object (Crocker, Knoeferle, & Mayberry, 2010). For example, participants fixate more on the apple than on the peach when they hear the word *apple*. Second, participants fixate more on an object that is going to be mentioned than the one that is not going to be mentioned. For example, participants fixated more on the *cake* when they hear *the boy will eat the …* than when they hear *the boy will move …* (Altmann & Kamide, 1999).

We use the statement *only if* φ, ψ as an example to illustrate how the visual world paradigm can be used to investigate the online processing of different sentential connectives (similar things happen to the statement *even if* φ, ψ). First, hearing the sentential connective *only if …* participants immediately realise that the statement is complex. This complex statement merges two simple propositions φ and ψ. Furthermore, the two simple propositions have to fulfil two requirements: when φ is true ψ is true (4a); and when φ is false ψ is also false (4b). To determine the appropriate option for φ, participants need to search all the possible options for φ and ψ in the visual domain. This search process will demand more visual attention and more fixations on the appropriate option for φ. Second, upon hearing *only if* φ … participants know what φ is. Knowing φ allows participants to determine what is *not-* φ, and this yields the the second meaning component *not-* φ *not-* ψ. This knowledge will demand more visual attention and more visual fixations to the *not-* φ cases. Third, hearing the whole statement *only if* φ, ψ allows participants to determine the statement's truth value. If ψ is true when φ is true and ψ is false when φ is false, the statement *only if* φ, ψ is true. Otherwise, the *only if* statement is false. This computational process happens after the offset of the whole test sentence and does not have an effect on participants' eye movements.

In the concurrent image, we visually presented three options for φ_x: φ_1, φ_2, φ_3 as in (6a–c) and two options for ψ_x: ψ_1, ψ_2 as in (7a and 7b). We further combined the three options for φ_x and the two options for ψ_x into three distinct events φ_x ψ_x: φ_1 ψ_1, φ_2 ψ_1, φ_3 ψ_2 as in (8a–c).

(6) Three options of φ_x
  (a) φ_1*: Astroboy helped the camel.*
  (b) φ_2*: Astroboy helped the rooster.*
  (c) φ_3*: Astroboy helped the peacock.*
(7) Two options of ψ_x
  (a) ψ_1*: Astroboy got a carrot as a reward.*
  (b) ψ_2*: Astroboy got a hamburger as a reward.*
(8) Three different events φ_x ψ_x
  (a) φ_1 ψ_1: *Astroboy helped the camel. Astroboy got a carrot as a reward.*
  (b) φ_2 ψ_1: *Astroboy helped the rooster. Astroboy got a carrot as a reward.*
  (c) φ_3 ψ_2*: Astroboy helped the peacock. Astroboy got a hamburger as a reward.*

Under this experimental manipulation, the three events (8a–c) either are compatible with the *only if* φ_x ψ_x statement, or are compatible with the *even if*

φ_x ψ_x statement, but not both, depending on the actual φ_x and ψ_x propositions that are merged. On one hand, if φ_3 is chosen as φ_x,then ψ_2 should be chosen as ψ_x. We then have one φ, ψ meaning component: φ_3 ψ_2 and two *not-* φ *not-* ψ meaning components: φ_1 ψ_1 and φ_2 ψ_1. But we do not have a *not-* φ ψ meaning component. In this case, the three events are compatible with the *only if* φ_3, ψ_2 statement; but are not compatible with the *even if* φ_3, ψ_2 statement. On the other hand, if we regard φ_1 as $\varphi_{x,}$ then ψ_1 should be regarded as ψ_x. We then have one φ ψ meaning component: φ_1 ψ_1; one *not-* φ ψ meaning component φ_2 ψ_1; and one *not-* φ ψ meaning component: φ_2 ψ_1. In this case, the three events are compatible with the *even if* φ_1, ψ_1 statement; but are not compatible with the *only if* φ_1, ψ_1 statement. A similar situation happens if we regard φ_2 as φ and ψ_1 as ψ.

On a typical trial, we first presented participants with a short animation to introduce the three options for φ (6a–c), two options for ψ (7a and 7b), and the three events of φ_x ψ_x: φ_1 ψ_1, φ_2 ψ_1, φ_3 ψ_2 (8a–c). This short animation described a story about the superhero Astroboy and the three animals: a camel, a rooster, and a peacock. At the beginning, the camel and the rooster had two carrots each, and the peacock had two hamburgers. The superhero did not have any reward. In the animation, the Astroboy first helped the camel, and got a carrot from the camel as a reward. The Astroboy then helped the rooster and got a second carrot from the rooster as a reward. Finally, the Astroboy helped the peacock, and got a hamburger from the peacock as a reward. At the end of the animation, the superhero Astroboy had two carrots and one hamburger; the camel had one carrot left, and so did the rooster; and the peacock had one hamburger left.

We then recorded participants' eye movements on the closing scene of the animation, when they were listening to one of the test sentences (9a–c).

(9) English translations of the Mandarin test sentences used in this study
- (a) *Once, Astroboy helped the __A__. He got a __B__ as a reward.*
- (b) *Only if Astroboy helped the __A__, he got a __B__ as a reward.*
- (c) *Even if Astroboy helped the __A__, he got a __B__ as a reward.*

If participants utilise the sentential connective *only if* or *even if* to determine the appropriate option for φ and ψ, we make the following observations.

First, upon hearing the sentential connective *even if* or *only if,* participants should know what the first proposition φ_x is. On one hand, upon hearing the sentential connective *only if* …, participants will know that the first simple proposition φ_x to be merged is φ_3 (6c), but is not φ_1 or φ_2 (6a or 6b). In this experimental design, hearing the sentential fragment *only if Astroboy helped the* … (9b) informs participants that *A* is *peacock* but not *camel* or *rooster*. This anticipation effect should result in more fixations on *peacock* in the closing scene of the animation. This anticipation occurs only if participants simultaneously accessed the two meaning components of the sentential connective *only if*: φ ψ and *not-* φ *not-* ψ. On the other hand, hearing the connective *even if* … informs participants that the first simple proposition φ_x to be merged is either φ_1 or φ_2 (6a or 6b) but is not φ_3 (6c). In our experimental design, hearing the sentential fragment *even if Astroboy helped the* … (9c) informs participants that *A* is either *camel* or *rooster*, but is not *peacock*. This anticipation effect should result in more fixations on *camel* and *rooster* in the closing scene of the animation. This anticipation occurs only if participants simultaneously accessed both the two meaning components of the sentential connective *even if*: φ ψ and *not-* φ ψ. As a control, upon hearing the word *once* in the complex statement *once* φ *and* ψ, participants are unable to know what φ_x is, before they hear it.

Second, hearing the first proposition φ_x informs participants what the first proposition φ is. This knowledge will trigger more fixations on the *not-* φ_x options, when the proposition φ_x is preceded by the sentential connective *only if* or *even if* than when the same proposition φ_x is preceded by *once*. This effect occurs no matter what the sentential connective is and no matter what the first proposition φ_x participants heard. As we described, both an *only if* φ, ψ and an *even if* φ, ψ have two meaning components: one meaning component where both of the merged propositions are true, i.e., φ ψ (4a) and (5a); the second meaning component involving false a first proposition φ, such as *not-* φ *not-* ψ (4b) in the *only if* φ, ψ statement (4), and *not-* φ ψ (5b) in the *even if* φ, ψ statement (5). A conjunctive statement *once*, φ *and* ψ like (3) has only one meaning component where both propositions are true, i.e., φ ψ like (3a). In our experimental design, once participants hear the first proposition φ (6a), they know the event φ ψ like (8a). The event φ ψ (8a) is the first meaning component of the complex statements *only if* φ, ψ (4) and *even if* φ, ψ (5) and is the only meaning component of the statement *once* φ *and* ψ (3). So the *not-* φ events (8b and 8c) are critical to determine the appropriateness of uttering the *only if* φ, ψ statement (4) and the *even if* φ, ψ statement (5), but are not critical to determine the appropriateness of uttering the *once* φ *and* ψ statement (3). Consequently, hearing *only if/even if Astroboy helped the camel* … should trigger more fixations on rooster and peacock, than hearing *once, Astroboy helped the camel* … . And hearing *only if/even if Astroboy helped the peacock* … should trigger more fixations on camel and rooster, than hearing *once, Astroboy helped the peacock* … .

2. THE STUDY

2.1. Participants

Forty-three students from the Beijing Language and Culture University took part in the experiment. All participants were native speakers of Mandarin Chinese and had normal or corrected normal vision. They were paid 30CNY (about $5) for their participation.

2.2. Stimuli and design

In the experiment, we preceded the presentation of the concurrent test images and the test audios with a short animation, to familiarise participants with the content of the test image and to make the use of the test sentences more natural. We developed the animations with Blender 2.57, free software running on a Mac system, at 24 frames per second. Figures 1 and 2 illustrate an example of the opening and closing scenes of an animation. A trial encompassed a superhero, such as Astroboy; three animals, such as a camel, a peacock, and a rooster. Initially, the superhero did not have any reward and each animal had two rewards (Figure 1). Two of the three animals' rewards were of the same type, e.g., the camel and the rooster had two carrots each. The third animal's rewards were different from the other two animals', e.g., the peacock had two hamburgers. In the animation, the superhero first performed an action (e.g. offering help) to one animal, and got a reward from that animal. On each trial, the superhero performed three actions, one time to each animal. The temporal order when an animal received the action and the characters' spatial positions were counterbalanced across trials. At the end of the animation, the superhero had three rewards of two categories, and each animal had only one reward left (Figure 2). A test sentence was then auditorily presented, accompanied by a test image that was the same as the closing scene of the animation.

This study was a 3 × 2 × 2 design. First, we developed two connectives, *only if*, *even if*, and a control condition, *once … and …* . Second, the first proposition's object had two levels. On half of the trials, the object referred to the animals that have the same rewards, such as *camel*. On the other half, the object referred to the animals that have the unique rewards, such as *peacock*. Third, the

Figure 1. The initial scene of the animation. Astroboy does not have any reward. Each animal has two rewards.

second proposition's object also had two levels. On half of the trials, the object referred to the unique reward, such as *hamburger* in our example; on the other half, the object referred to the reward shared by the two animals, such as *carrot* in our example. We recruited a female Mandarin-speaker from Beijing to record the test audios. We recorded the test sentences in a word-by-word fashion, to make the test sentences the same in length (i.e., 10,000 ms each) and the same in prosody, as the prosody might have an effect on the sentence interpretation (Figure 3).

We divided the experiment into two blocks: a practice block and an experimental block. Practice blocks included eight trials, to familiarise participants with the experimental procedure. Experimental block consisted of 24 experimental trials, with 8 trials with each connective, and 13 fillers like *Astroboy first helps a camel. He then helps a peacock* (See Appendix for the complete list of test sentences). We presented the trials in a pseudo-randomised way, so that two neighbouring trials had different connectives. The whole experiment lasted about 35 minutes.

2.3. Procedure

Participants were seated approximately 65 cm from a 21 inch 4:3 colour monitor with 1024 × 768 pixel resolution. Twenty-four pixels equaled about 1° of visual angle. Participants wore a SR Research Eyelink II head-mounted eye-tracker running at a 500 Hz sampling rate. Viewing was binocular, but only the participant's dominant eye was tracked. Participants were instructed to avoid sudden head movements throughout the experiment. The auditory stimuli were presented via a pair of external speakers situated to the left and right of the monitor. The recordings were played from the hard disc as 24 khz mono sound clips. Stimulus presentation and data recording were controlled by two PCs running software developed by SR research Ltd. The keyboard of the data presentation PC was used to record participants' button responses.

At the beginning of the experiment, participants saw a brief introduction to the experiment on the screen in Mandarin Chinese. The experimenter then helped the participant to wear the Eye-tracker and performed the standard Eyelink calibration routine, which involved participants looking at a grid of nine fixation targets in random succession. Then a validation phrase followed to test the accuracy of the calibration against the same targets. If the average error of validation was greater than 1°, the routine was then repeated. This routine was carried out at the beginning of each block, and whenever the experimenter noticed that the measurement accuracy was poor (e.g., after head movements or a change in the participant's posture).

Each trial was structured as follows: participants first saw the trial number in the middle of the screen. Four seconds later, or pressing the SPACE key brought up a short animation. A black dot

Figure 2. The closing scene of the animation, and the test scene. Astroboy has three rewards and each animal has only one reward left. This is because Astroboy helped the three animals three times, one time for each animal. And he got a reward after each help.

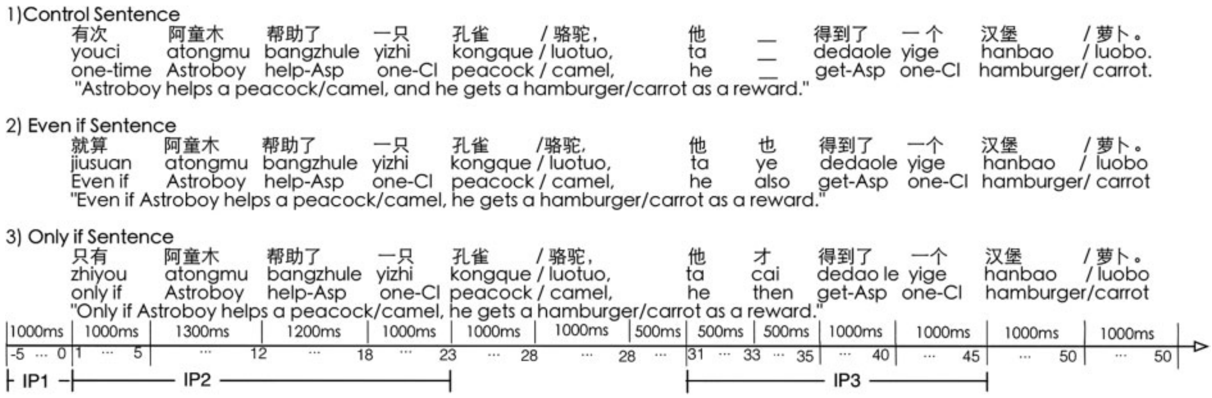

Figure 3. An example of the complete list of the test sentences used in this study. We have three connectives, with the objects of its two propositions were counterbalanced. In the real experiment, only one test sentence was related to one contextual animation. The counterbalance was carried out between different trials. 1000 ms, … are the length of each linguistic element in Mandarin Chinese; –5 … 50 are the temporal bins of 200 ms long each; and *IP1, IP2, IP3* are the temporal periods that we are interest in.

appeared at the centre of the screen when the animation was finished. The participant was instructed to press the SPACE key when fixating at the dot. This was a drift correction process. This press brought up the test image. The auditorily presented test sentence was then played 1,000 ms after the onset of the test image. The test picture remained on the screen for 2,000 ms after the offset of the spoken sentence. Each test sentence was 10,000 ms long, so a test picture was presented for about 12,000 ms. Participants' eye movements were recorded during this 11,000 ms, from the onset of the test image to the offset of the test audio. Participants were instructed to view the animation and pictures, and to listen to the sentences attentively. Pressing a key or 4,000 ms later brought up a new trial, with the trial number appearing in the middle of the screen.

3. RESULTS

In preparing the data, we pooled the fixations shorter than 80 ms with the preceding or following fixations if they were within 0.5° of visual angle, otherwise we deleted them. This was because short fixations are a result of false saccade planning rather than meaningful information processing, and readers do not extract much information during such short fixations (Rayner & Pollatsek, 1989). We deleted two participants from further analysis, because of too many tracking losses. We then equal divided the test scene into four interest areas: The superhero with the three rewards he received, and the three animals with the reward it had left. We then partitioned the 11,000 ms temporal period from the onset of the test image to the offset of the test audio into 55 temporal bins, each 200 ms long. The dependent variable was the proportion of fixations to an animal in a temporal frame divided by all fixations recorded in that temporal frame. For example, if there were four fixation points in a temporal bin, with one point located in the interest area, then the proportion was ¼. If no fixation was recorded in that temporal bin, then the proportion of fixations was coded as zero. It is possible to record two fixations in one temporal frame, so the dependent variable was not strictly binary.

To report the data, we first produced a descriptive diagram of participants' proportions of fixations. We then fitted the data into generalised linear mixed-effects models. In these models, the connectives and the temporal bins were fixed effects, and the random effects included the intercepts and slopes of both participants and items for each fixed effect (Baayen, Davidson, & Bates, 2008). The fixed effect *connective* was a factor with three levels: *control*, *even if* and *only if*. The temporal bins were grand-mean centred and measured in seconds rather than in milliseconds, to avoid issues involving collinearity when conducting the analysis of the bins. Since participants' eye movements are not necessarily linearly related to the temporal bins, we also included the quadratic and cubic time in the models (Mirman, Dixon, & Magnuson, 2008). The exact model we used can be found under table presenting the data. We conducted the fitting process via functions *lmer* in package *lme4* (*version 0.999999-2;* Bates, Maechler, & Bolker, 2013) using *R* software environment (v3.01; R Development Core Team, 2010).

We then treated the *t* statistical values as if these were *z* scores (i.e., using the standard normal distribution as a reference) before we calculated significance. We carried out the analyses on raw data with no aggregation, and every model used can be found at the bottom of the table reporting the results.

We were interested in three clusters of temporal bins: the first cluster ranges from the onset of the test image to the onset of the test audio, giving us a baseline of participants' fixation tendencies. The second cluster ranges from the onset of the test audio to the onset of the first proposition's object, telling us whether participants could incrementally utilise the conditional connectives to predict the objects that were going to be mentioned. The third cluster ranged from the onset of the second proposition to the onset of the second proposition's object, indicating how the unmentioned animals in the first propositions were accessed by different conditional connectives. We expand on these in the following paragraphs.

Figure 4 illustrates the participants' fixation patterns from the onset of the test images to the onset of the first proposition's object. To say that a connective had an effect, two requirements had to be fulfilled at the same time: no difference should exist between different conditions prior to the onset of the connectives; and a significance emerged after the onset of different connectives. So we fitted our statistical model to four data-sets divided by different interest areas and by the onset of the connectives.

As summarised in Table 1, the model fitting processes confirmed our predictions. First, no effect was observed before the onset of the test audio, setting up a valid baseline for further comparison. Second, significant effects of the connective were reported after the onset of the test audios. To be specific, the connective *even if* launched significantly more fixations to the two animals with the same rewards, such as the *camel* and *rooster* ($\beta = 0.06$, $t = 2.77$, $p < .01$); and the connective *only if* launched more fixations on the animal with a unique reward, such as the *peacock* ($\beta = 0.05$, $t = 2.35$, $p < .05$).

Third, we examined how the sentential connectives affected participants' fixations on the unmentioned objects, after the offset of the first proposition. Figure 5 displays participants' fixations on the unmentioned animals from the onset of the second proposition to the onset of the object of the second proposition.

We also fitted the model to two data-sets based on the object of the first proposition. As shown in Table 2, the unmentioned animals received significantly more fixations in the experimental conditions, compared to the control condition. To be specific, when *camel* was mentioned in the first proposition, both *only if* ($\beta = 0.06$, $t = 2.11$, $p < .05$) and *even if* ($\beta = 0.04$, $t = 2.37$, $p < .05$) triggered more fixations on the *peacock* and the *rooster* in the second proposition. Similarly, when *peacock* was mentioned in the first proposition, both *only if* ($\beta = 0.04$, $t = 2.06$, $p < .05$) and *even if* ($\beta = 0.04$, $t = 2.11$, $p < .05$) launched more

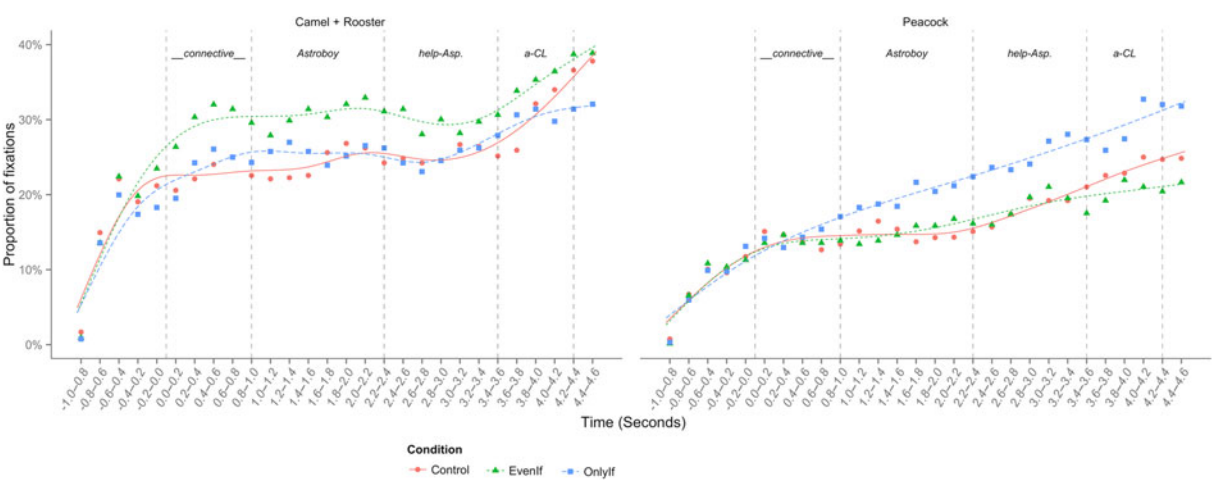

Figure 4. Participants' fixation patterns from the onset of the image to the onset of object of the first proposition. *y*-axis, the proportions of fixations; *x*-axis, the temporal period when the eye movements were recorded. The temporal bins smaller than zero happened prior to the onset of the test audios. For example, *–1.0–0.8* means that the data were recorded from 1 s to 0.8 s before the onset of the test audios. Left panel, i.e., *camel* + *rooster*, participants' fixations on the two animals with the same rewards; Right panel, i.e., *peacock*, participants' fixation patterns on the animal with unique rewards. [To view this figure in colour, please visit the online version of this Journal.]

TABLE 1
Fixed effects of the fitted model process from the onset of the test image to the onset of the first proposition's object

Temporal period	*Interest areas*	*Fixed effects*	*Estimate*	*Standard error*	*t value*	*p value*
Pre-sentence onset						
	Camel + Rooster					
		Intercept	2.0E – 01	3.2E – 02	6.35	2.1E – 10***
		Linear time	7.5E – 02	4.6E – 02	1.63	1.0E – 01
		Quadratic time	–5.6E – 01	6.5E – 02	–8.72	0.0E + 00***
		Cubic time	1.1E + 00	3.2E – 01	3.41	6.6E – 04***
		Even if	2.4E – 03	3.9E – 02	0.06	9.5E – 01
		Only if	–1.8E – 02	3.9E – 02	–0.46	6.4E – 01
	Peacock					
		Intercept	9.5E – 02	2.0E – 02	4.71	2.5E – 06***
		Linear time	6.8E – 02	3.6E – 02	1.91	5.6E – 02
		Quadratic time	–2.1E – 01	5.0E – 02	–4.23	2.3E – 05***
		Cubic time	4.8E – 01	2.5E – 01	1.94	5.3E – 02
		Even if	6.1E – 04	2.6E – 02	0.02	9.8E – 01
		Only if	3.0E – 04	2.6E – 02	0.01	9.9E – 01
Post-sentence onset						
	Camel + Rooster					
		Intercept	2.5E– 01	2.2E – 02	11.17	0.0E + 00***
		Linear time	–6.3E – 03	5.5E – 03	–1.15	2.5E – 01
		Quadratic time	7.0E – 03	1.9E – 03	3.62	3.0E – 04***
		Cubic time	8.2E – 03	1.7E – 03	4.69	2.7E – 06***
		Even if	5.6E – 02	2.0E – 02	2.77	5.6E – 03**
		Only if	4.5E – 03	2.0E – 02	0.22	8.2E – 01
	Peacock					
		Intercept	1.7E – 01	1.8E – 02	9.16	0.0E + 00***
		Linear time	3.1E – 02	4.8E – 03	6.44	1.2E – 10***
		Quadratic time	4.4E – 03	1.7E – 03	2.58	9.8E – 03**
		Cubic time	–5.1E – 04	1.5E – 03	–0.34	7.4E – 01
		Even if	–5.3E – 03	2.0E – 02	–0.26	8.0E – 01
		Only if	4.8E – 02	2.0E – 02	2.35	1.9E – 02*

Pre-sentence and post-sentence onset, the temporal periods divided by the onset of the test audio; *Camel + rooster*, participants' fixations on the two animals with the same rewards, such as the camel and the rooster; and *peacock*, participants' fixations on the animal with unique rewards, such as peacock.

Formula used in R: *proportions of fixation ~ Linear time + Quadratic Time + Cubic time + conditions + (1+ Linear time + Quadratic Time + Cubic time + conditions |subject) + (1+ Linear time + Quadratic Time + Cubic time + conditions |trial)*

$^{*}p < .05$; $^{**}p < .01$; $^{***}p < .001$.

fixations to the *camel* and *rooster* in the second proposition. No difference exists between the sentential connective *only if* and the connective *even if*.

To summarise, the two experimental predictions have been confirmed: first, the sentential connective *only if* and *even if* triggered more fixations on the reasonable animals that were going to be mentioned in the object of the first proposition φ; in the second proposition ψ of the test sentence, the sentential connectives *only if* and *even if* then initiated more fixations on the unmentioned animals, compared to the sentential connective *once … and* … These results suggest that sentential connectives can be used to find the appropriate version of the first proposition φ.

4. DISCUSSION

First, our results are in accordance with the mental model theory proposed by Johnson-Laird (1983, 2005, 2010) and Johnson-Laird and Byrne (2002). A mental model is a possibility that something will happen given the truth of a statement. A simple proposition has only one mental model; but a complex statement may have one or more mental models. Comprehending a statement is constructing all the mental models corresponding to that statement. The mental models corresponding to a complex statement depend on the sentential connective merging the simple propositions (Johnson-Laird, 2005). For example, φ *and* ψ have only one mental model where both the merged propositions φ and ψ are true. Byrne (2005) has proposed that:

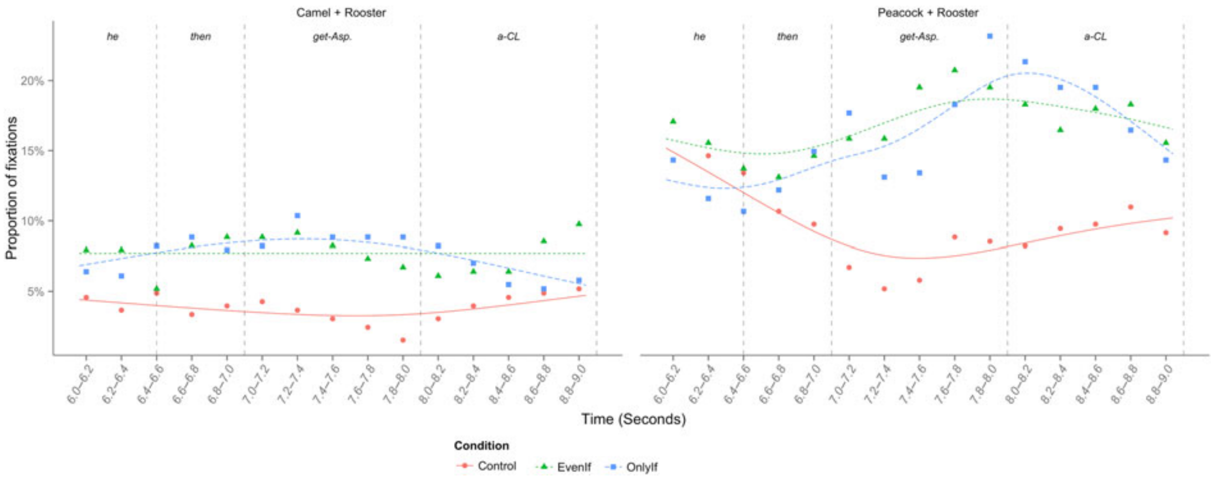

Figure 5. Participants' fixation patterns on the unmentioned animals from the onset of the second proposition to the onset the second proposition's object. Left panel, i.e., *peacock + rooster*, participants' fixations on the two remaining animals, such as peacock and rooster, when the object of the first proposition was one of the animal that shared the rewards, such as *camel*; Right panel, i.e., *camel + rooster*, participants' fixations on the two remaining animals, such as camel and rooster, when the object of the first proposition was the animal with unique rewards, such as *peacock*. [To view this figure in colour, please visit the online version of this Journal.]

(1) an *only if* φ*, then* ψ statement has two mental models: φ ψ where both the merged propositions are true, and *not-* φ *not-* ψ where both the merged propositions are false; (2) an *even if* φ, ψ statement has two different mental models: φ ψ where both the merged propositions are true and *not-* φ ψ where the first merged proposition is false and the second merged proposition is true. Our results are in accordance with this proposal.

Second, our results are also in accordance with the experimental studies reported in literature (Egan et al., 2009; Johnson-Laird & Byrne, 1989; McCloy & Byrne, 2002; Moreno-Ríos et al., 2008; Santamaría & Espino, 2002; Santamaría et al., 2005). The self-paced reading task has been used to study conditional statements like *only if* φ, ψ and *even if* φ, ψ. With this task, participants first read a statement, then read a possibility.

TABLE 2

Fixed effects of the fitted model for the unmentioned animals from the onset of the second proposition to the onset of the object of the second proposition

Interest areas	*Fixed effects*	*Estimate*	*Standard error*	*t value*	*p value*
Peacock + Rooster					
	Intercept	9.6E – 02	2.4E – 02	3.99	6.7E – 05***
	Linear time	4.1E – 02	1.1E – 02	3.73	1.9E – 04***
	Quadratic time	1.1E – 03	5.6E – 03	0.19	8.5E – 01
	Cubic time	–2.5E – 02	7.5E – 03	–3.32	8.9E – 04***
	Even if	7.1E – 02	3.0E – 02	2.37	1.8E – 02*
	Only if	6.3E – 02	3.0E – 02	2.11	3.5E – 02*
Camel + Rooster					
	Intercept	3.9E – 02	1.6E – 02	2.50	1.2E – 02*
	Linear time	–1.3E – 02	7.7E – 03	–1.66	9.7E – 02
	Quadratic time	–1.9E – 03	3.9E – 03	–0.49	6.3E – 01
	Cubic time	8.3E – 03	5.3E – 03	1.58	1.1E – 01
	Even if	3.9E – 02	1.9E – 02	2.11	3.5E – 02*
	Only if	3.8E – 02	1.9E – 02	2.06	3.9E – 02*

When *camel* was mentioned in the object of the first proposition, the result shows participants' fixations on the peacock and the rooster. When *peacock* was mentioned in the object of the first proposition, then the results show participants' fixations on the camel and rooster.

Formula used in R: *proportions of fixation ~ Linear time + Quadratic Time + Cubic time + conditions + (1+ Linear time + Quadratic Time + Cubic time + conditions |subject) + (1+ Linear time + Quadratic Time + Cubic time + conditions |trial)*

*$p < .05$; ***$p < .001$.

Comprehending a statement activates all its mental models. So participants read a possibility quicker when the possibility is a mental model of the preceding statement, than when the possibility is not a mental model of the preceding statement. The reading time of a possibility will tell us whether or not a possibility is a mental model of a statement. Previous studies have found that participants read the possibility *not-* φ *not-* ψ quicker when it is preceded by *only if* φ, ψ, than when it is preceded by *if* φ, ψ (Santamaría & Espino, 2002). Similarly, participants read the possibility *not-* φ, ψ faster when it is primed by *even if* φ, ψ than when by *if* φ, ψ (Santamaría et al., 2005). These results suggest that the possibility *not-* φ *not-* ψ is a mental model of the statement *only if* φ, ψ; and the possibility *not-* φ ψ is a mental model of the *even if* φ, ψ statement. Conditional reasoning tasks have also been used to test the meaning of the statements like *only if* φ, ψ and *even if* φ, ψ. With a conditional reasoning task, participants first suppose both a complex statement like *only if* φ, ψ or *even if* φ, ψ and a simple proposition like φ, *not-* φ, ψ, or *not-* ψ as true; participants then judge whether or not a second simple proposition like ψ, *not-* ψ, φ, *or not-* φ is true. Using the conditional reasoning task, Egan et al. (2009) observed that when a complex statement *only if* φ, ψ and a simple proposition *not-* φ are both true, participants tend to think *not-* ψ is also true. This supports the idea that *not-* φ *not-* ψ is a meaning component (or mental model) of the complex statement *only if* φ, ψ. Similarly, Handley and Feeney (2004) observed that when a complex statement *even if* φ, ψ and a simple proposition *not-* φ are true, participants tend to think *not-* ψ is false, or ψ is true. This result supports the idea that *not-* φ ψ is a meaning component (or mental model) of the complex statement *even if* φ, ψ. So our results are both in alignment with the mental model theory proposed by Johnson-Laird (1983, 2005, 2010) and Johnson-Laird and Byrne (2002), and with the experimental results reported in literature (Egan et al., 2009; Johnson-Laird & Byrne, 1989; McCloy & Byrne, 2002; Moreno-Ríos et al., 2008; Santamaría & Espino, 2002; Santamaría et al., 2005). All this suggests that an *only if* φ, ψ has two meaning components: φ ψ, and *not-* φ *not-* ψ. An *even if* φ, ψ statement also has two meaning components: φ ψ, and *not-* φ ψ. [Note: as one anonymous reviewer mentioned, the test sentences Santamaría and Espino (2002) and Santamaría et al. (2005) used are actually ψ *only if* φ, rather than *only if* φ, ψ. But we are going to suppose that ψ *only if* φ and *only if* φ, ψ have the same meaning. Readers can read Santamaría and Espino (2002) and Santamaría et al. (2005) for more discussion.]

Third, the results help us to adjudicate between different theories of *even.* Three main accounts of *even* (*if*) have been proposed in the literature: the existential account (Bennett, 1982; Francescotti, 1995), the scalar account (Barker, 2003; Declerck & Reed, 2001; Fauconnier, 1975; Kay, 1990), and the universal account (Barker, 1991; Lycan, 1991, 2001). According to the existential account, an *even if* φ, ψ statement like (10) is true as long as mental models φ ψ (10a) and *not-* φ ψ (10b) both exist in the context. Whether or not the mental model *not-* φ *not-* ψ (10c) exists in the context is irrelevant to the truth of the *even if* φ, ψ statement. Nevertheless, the scalar account and the universal accounts suppose that the existing of the two mental models φ ψ (10a) and *not-* φ ψ (10b) are necessary but are not sufficient to make the *even if* φ, ψ (10) statement true. The *even if* φ, ψ (10) statement is true only if the mental model *not-* φ *not-* ψ (10c) does not exist in the context. In our experimental design, the third mental model *not-* φ *not-* ψ (10c) actually exists. So if the non-existence of *not-* φ *not-* ψ (10c) is a prerequisite condition for the statement *even if* φ, ψ to be true, it is unlikely to observe the effect of the sentential connective *even if* … . And the observed effect then suggests that this non-existence is not necessarily a prerequisite condition for the truth of an *even if* statement.

(10) *Even if Astroboy helped the camel, he got a carrot as a reward.*
  (a) *Astroboy helped the camel. Astroboy got a carrot as a reward.*
  (b) *Astroboy helped the rooster. Astroboy got a carrot as a reward.*
  (c) *Astroboy helped the peacock. Astroboy got a hamburger as a reward.*

Fourth, the results also shed some light on the difference between *only if* and *even if.* As we discussed in the third point, the non-existence of the mental model *not-* φ *not-* ψ is not a prerequisite for the *even if* φ, ψ statement to be true. And the *even if* φ, ψ statement is true as long as the two mental models φ ψ and *not-* φ ψ exist in the context. In this sense, the *even if* φ, ψ statement is inclusive. On the contrary, the statement *only if* φ, ψ is true if and only if the two conditions are fulfilled at the same time: (1) the two mental models φ ψ and *not-* φ *not-* ψ exist in the context;

and (2) the mental model *not-* φ ψ does not exist in the context. In this sense, the *only if* φ, ψ statement is exclusive. Participants need to search all the events in the context before they can determine whether or not the statement *only if* φ, ψ is true. This is probably the reason why the effect of the *only if*—connective emerges later in time than that of an *even if*—connective.

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APPENDIX: TEST SENTENCES USED IN THIS STUDY

(a) Practice block

Only If

01 只有阿童木认识了那只小猫，他才得到了一张光盘。
Only if Astroboy met the cat, he got a disc as a gift.

02 只有阿童木认识了那只天鹅，他才得到了一张椅子。
Only if Astroboy met the swan, he got a chair as a gift.

Even If

03 就算阿童木认识了那只天鹅，他也得到了一张椅子。
Even if Astroboy met the swan, he also got a chair as a gift.

04 就算阿童木认识了那只小猫，他也得到了一张光盘。
Even if Astroboy met the cat, he also got a disc as a gift.

Control

05 有次阿童木认识了那只天鹅，他__得到了一张椅子。
Once, Astroboy met the swan, and he got a chair as a gift.

06 有次阿童木认识了那只天鹅，他__得到了一张光盘。
Once, Astroboy met the swan, and he got a disc as a gift.

Filler

07 阿童木首先认识了那只企鹅，然后认识了那只小猫。
Astroboy first encountered the penguin; he then encountered the cat.

08 阿童木首先认识了那只小猫，然后认识了那只天鹅。
Astroboy first encountered the cat; he then encountered the swan.

(b) Experimental block

Only If

09 只有机器猫看望了那只青蛙，他才得到了一块石头。
Only if Doraemon visited the frog, he got a rock as a gift.

10 只有史努比打败了那只孔雀，他才得到了一个鸡蛋。
Only if Snoopy defeated the peacock, he got an egg as a reward.

11 只有跳跳虎背起了那只海豚，他才得到了一个茄子。
Only if Tigger carried the dolphin on his back, he got an eggplant as a reward.

12 只有蝙蝠侠阻止了那只狐狸，他才得到了一个辣椒。
Only if Batman stopped the fox (from doing something bad), he got a pepper as a gift.

13 只有泰迪熊看见了那只小羊，他才得到了一个萝卜。
Only if Teddy the Bear found the lamb, he got the carrot as a reward.

14 只有小仙女战胜了那只公鸡，他才得到了一个玉米。
Only if the fairy defeated the rooster, he got a corn as a reward.

15 只有灰太郎拥抱了那只兔子，他才得到了一个菠萝。
Only if Grey Wolf embraced the rabbit, he got a pineapple as a gift.

16 只有老巫婆打败了那只老鹰，他才得到了一个桔子。
Only if the old witch defeated the eagle, she got an orange as a reward.

Even If

17 就算灰太郎邀请了那只绵羊，他也得到了一条虫子。
Even if Gray Wolf invited the sheep (to his party),he also got a worm as a gift.

18 就算小男孩照顾了那只蜘蛛，他也得到了一颗蔬菜。
Even if the boy took cared of the spider, he also got a vegetable as a reward.

19 就算小女孩阻止了那只考拉，他也得到了一条小鱼。
Even if the girl stopped the koala (from doing something bad), he also got a fish as a reward.

20 就算跳跳虎追上了那只鸭子，他也得到了一支羽毛。
Even if Tigger caught up the duck, he also got a feather as a reward.

21 就算喜洋洋碰见了那只母鸡，他也得到了一条裙子。
Even if Happy Goat encountered the hen, he also got a skirt as a gift.

22 就算阿童木帮助了那只骆驼，他也得到了一个汉堡。
Even if Astroboy helped the camel, he also got a hamburger as a reward.

23 就算喜洋洋照顾了那只老虎，他也得到了一个茄子。
Even if Happy Goat took care of the tiger, he also got an eggplant as a reward.

24 就算维尼熊帮助了那只袋鼠，他也得到了一个面包。
Even if Winnie the Pooh helped the kangaroo, he also got bread as a reward.

Control

25 有次老巫婆看望了那只绵羊，他__得到了一条裙子。
Once, the old witch visited the sheep, and she got a skirt as a gift.

26 有次灰太郎背起了那只蝴蝶，他__得到了一颗草莓。
Once,Gray wolf carried the butterfly on his back, and he got a strawberry as a gift.

27 有次维尼熊认识了那头狮子，他__得到了一根香蕉。

Once, Winnie the Pooh met the lion, and he got a banana as a reward.

28 有次加菲猫拥抱了那头小猪，他__得到了一颗蔬菜。
Once, Garfield embraced the pig, and he got a vegetable as a gift.

29 有次蝙蝠侠阻止了那只蚂蚱，他__得到了一颗星星。
Once,Batman stopped the grasshopper (from doing something bad), and he got a vegetable as a reward.

30 有次唐老鸭追上了那条鳄鱼，他__得到了一台冰箱。
Once, Donald Duck caught up the crocodile, and he got a fridge as a reward.

31 有次蝙蝠侠遇见了那只母鸡，他__得到了一条裤子。
Once, Batman met the hen, and he got a pair of trousers as a gift.

32 有次米老鼠打败了那头驴子，他__得到了一根骨头。
Once, Mickey Mouse defeated the donkey, and he got a bone as a reward.

Filler

33 喜洋洋首先邀请了那只蚂蚁，然后邀请了那只蜘蛛。
Happy Goat first invited the ant (to a party); he then invited the spider.

34 小仙女首先拥抱了那只鸭子，然后拥抱了那只企鹅。
The fairy first embraced the duck; she then embraced that penguin.

35 机器猫首先遇见了那条金鱼，然后遇见了那条鲨鱼。
Doraemon first encountered the goldfish; he then encountered the shark.

36 史努比首先照顾了那只小狗，然后照顾了那只恐龙。
Snoopy first took care of the dog; he then took care of the dinosaur.

37 有次泰迪熊背起了那头大象，他也得到了一杯红酒。
Teddy the Bear first met the elephant; he then met the pig.

38 加菲猫首先战胜了那只天鹅，然后战胜了那只乌龟。
Garfield first defeated the swan; he then defeated the turtle.

39 唐老鸭首先碰见了那只小羊，然后碰见了那只青蛙。
Donald Duck first met the goat; he then met the frog.

40 有次米老鼠追上了那只青蛙，他也得到了一块西瓜。
Micky Mouse first caught up the frog; he then caught up the turtle.

41 唐老鸭首先战胜了那头小猪，然后战胜了那头狮子。
Donalk Duck first defeated the pig; he then defeated the lion.

42 小男孩首先邀请了那只企鹅，然后邀请了那只鸵鸟。
The boy first invited the penguin (to his party);he then invited the ostrich.

43 小女孩首先认识了那只兔子，然后认识了那只老虎。
The girl first met the rabbit; he then met the tiger.

44 泰迪熊首先遇见了那条鳄鱼，然后遇见了那条金鱼。
Teddy the Bear first met the crocodile; he then met the goldfish.

45 机器猫首先帮助了那只犀牛，然后帮助了那只绵羊。
Doraemon first helped the rhino; he then helped the sheep.