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QUESTIONING THE RULES OF CONTINUITY EDITING: AN EMPIRICAL STUDY

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ABSTRACT

We investigated phenomenal continuity across mid-action cuts in motion pictures. When a change of perspective is used in the midst of a dynamic event, film directors tend to agree that a straight-match cut is not advisable if the impression of smooth continuity is desired. Such a cut would embody an instantaneous transition from one camera angle or position to the next. Some film theorists recommend that some overlap of the action is desirable, surmising that the visual system needs time to digest the cut and to reorient. Others disagree and prefer a gap. We report two experiments that provide an empirical test of competing continuity hypotheses. We systematically varied the temporal parameters of a dynamic scene that continued across a camera jump. Computer-animated sequences had to be adjusted until they looked maximally smooth and temporally correct. Observers very consistently preferred gaps (ellipses). Implications for film editing and film theory are discussed.

INTRODUCTION

This article evaluates the phenomenal experience of continuity or discontinuity that arises when a cut is introduced within an action scene in a movie. We do so by bringing together two rather separate domains. On the one hand, film makers and film theorists have collected experiential and aesthetic guidelines as to how a

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given cut affects the percept of continuity. On the other hand, experimental psychology has gathered know-how that allows us to measure subjective impressions of continuity. By merging the two domains we attempt to answer the question which editing rules are grounded on empirical psychology and which rules reflect aesthetics or convention? We first summarize some of the salient recipes for cuts formulated by film theory. We then test if these recipes are grounded in perceptual psychology. This was accomplished with the help of two experiments in which students had the opportunity to modify an artificial film scene to make it appear smooth and continuous.

Perceptual Continuity

The stable and continuous visual appearance of the world is by no means a trivial achievement of our visual system. "Indeed, one of the central problems in vision is how a stable world is perceived when eye movements occur; that is, how continually changing retinal images (i.e., the proximal stimuli) are mapped onto a stable representation of the world (i.e., the distal stimulus)" (Breitmeyer, Kropfl, & Julesz, 1982, p. 176). The visual system is quite obviously able to discount the better part of all retinal movements. It reliably detects movement in the world regardless of whether or not we move our head or eyes during the process. Some of the basic mechanisms that are responsible for this feat (see, e.g., Gibson, 1979) may also allow us to perceive a continuous world inside the visual narrative of a film. One could argue that the phenomenal continuity that we achieve across film cuts is even more remarkable a feat than perceiving a stable world. We are able to perceive continuity in the face of considerable camera displacements.

Rudolf Arnheim (1971/1933) remarks that one of the distinctive features of film is its ability to violate the spatial and temporal continuity which reigns in the real world. Not only have violations of continuity become commonplace in film, but temporal and spatial discontinuities appear to be an inevitable means of storytelling in film. A few notable exceptions exist, such as *Rope* by Alfred Hitchcock. Nonetheless, phenomenal continuity must be preserved. Film cuts may violate real world continuity only insofar as they maintain phenomenal continuity. Thus, phenomenal continuity is the measuring stick when it comes to evaluating the extent to which spatio-temporal jumps are permissible in film. Surprisingly, perceptual psychologists have not yet spelled out the laws that are able to describe phenomenal continuity. Film makers and film theorists, on the other hand, have collected rules and guidelines for phenomenal continuity. We have put some of these rules to an empirical test.

Continuity Editing in Film

Filmic storytelling has in its early stages engendered the concept of continuity editing. Whenever a coherent filmic story is visually interrupted by a cut, the transition between shots can be accomplished in various fashions. Beller (1993) traces the term "continuity" in Anglo-American filmmaking as far back as the year 1910, when continuity had already been applied both to cuts where the action remains in a given place and to cuts between locations. Subsequently, several film experts have formulated rules about the nature of cuts. For instance, Noël Burch (1973/1969) formulated a "Praxis du Cinéma," that is a "Theory of Film Practice." Burch begins by describing "possible forms of temporal and spatial articulations between two shots" (p. 4). In a chapter on the breakdown of film narrative by cutting technique (découpage), Burch then aptly distinguishes between the "straight-match cut," the "temporal ellipsis," and the "time reversal." The straight-match cut leaves the temporal structure of the action unchanged while switching from one camera to another. The temporal ellipsis leaves a piece, often as little as a few frames, on the cutting floor such that a temporal gap arises. According to Burch (p. 6f), this is the most commonly used technique. The third cut, time reversal, is an avant-garde technique that introduces an overlap. That is, the action of the second camera backs up and the overlapping frames are shown first from camera position 1 and then again from position 2. We prefer to call this overlap replication.

Dmytryk (1984), who is among the few directors who have attempted to spell out rules of film editing, seems to be in disagreement with Burch (1973/1969). First, Dmytryk suggests that a cut will only look smooth if it is made while the scene is in motion: "Whenever possible, cut 'in movement'" (p. 27). He goes on to suggest that, unlike commonly believed, a change in image size is not required. And most importantly, an action overlap of three to five frames should be introduced. At 24 frames per second this demanded overlap would range from 125 to 208 ms. Similarly, Anderson (1996, p. 100), states that one of the four rules of continuity editing is to overlap the action (i.e., time reversal) by about two frames. At 24 frames per second this demanded overlap would amount to approximately 83 ms.

Reisz and Millar (1968) claim from their experience that spatial continuity is easily achieved when actors and objects are stationary in the world, whereas the impression of temporal continuity is rather difficult to achieve when the camera position changes while the actors or objects are in motion. In the latter case, the cutter has to make sure the moving object is in the exact same world location immediately before and after the cut. Whenever a part of the movement is either left out or repeated, the observer will receive an impression of jumpiness. A phenomenal lack of continuity will ensue and the motion will lose its smoothness.

In contrast to these suggestions, Mehnert (1963) holds that a mid action cut has to be made physically discontinuous in order to appear continuous. Flowing continuity can only be achieved if part of the action is cut. That is, Mehnert proposes to introduce a gap, an ellipsis to achieve phenomenal continuity.

Anderson (1996; see above) makes the opposite proposition. He holds that the action should be overlapped by approximately two frames. In the same vein, Dmytryk (1984) favors an overlap (replication) by three to five frames. Finally, Levin and Simons (2000) contend that the sensitivity of observers is so low that it does not make a difference whether or not we introduce a gap or an overlap.

Observers are generally blind to many changes across cuts including spatio-temporal displacements (see e.g., Simons & Chabris, 1999).

It is rather striking that the experts in the field make seemingly contradictory suggestions as to how the cutter should treat a mid action cut. To put ourselves into a better position to evaluate the different recipes that have been proposed thus far, we carefully distinguish between temporal and spatial discontinuities. Regarding the temporal domain, transitions between successive/adjacent shots of an action scene may be *replicative*, *continuous,* or *elliptic* depending on whether the cutter has introduced an overlap, a straight match, or a gap, respectively. Regarding the spatial domain we distinguish between *enlargement*, *equidistance*, and *contraction.* An enlargement is the case when the setting shown by the first in a pair of such shots (e.g., a close-up) is spatially contained in the second (e.g., a medium shot). The opposite case is a contraction; only a part of the first setting is shown in the second shot. Spatial equidistance arises when the orientation of the camera is changed whereas the distance between camera and set remains unchanged. In making these distinctions, we follow Arnheim in spirit (1971/1933, p. 95). He had borrowed the term *enlargement* from Timoshenko, and we follow suit. However, in the case when the camera moves closer after the cut, Timoshenko's concentration, is, in our opinion, best denoted by *contraction.* The case of unchanged camera distance we prefer to call *equidistant*. The labels used in Table 1 show the potential combinations of the above mentioned forms of spatial and temporal discontinuity.

To conclude, we can discern three incompatible continuity hypotheses that all have some degree of intuitive plausibility, be it by virtue of an argument or be it by the authoritative support of experts in the field.

1. Straight-match (continuation) hypothesis (suggested by Reisz & Millar, 1968): A cut will appear discontinuous unless the new camera picks up the

Table 1. Classification of Temporal and Spatial Discontinuities. Note that Most Cells Cannot be Described by Standard Film Terms

		Temporal		
		Replication	Continuation	Ellipsis
Spatial	Enlargement	enlarging replication	straight match	enlarging ellipse
	Equidistance	replication	seamless continuity	ellipse
	Contraction	contracting replication	straight match	contracting ellipse

world action at exactly the point where the first camera has left off. Temporal but not spatial continuity is required.
2. Ellipsis hypothesis (entertained by Mehnert, 1963): An ellipsis is required to reach maximal perceived continuity.
3. Replication hypothesis (endorsed by Dmytryk, 1984, and Anderson, 1996): A replication is required to reach maximal perceived continuity.
4. Non-discrimination hypothesis (favored by Levin & Simons, 2000): Within limits, spatio-temporal discontinuities are not detected by the observer, and therefore straight match, ellipsis, and replication should all appear continuous.

Note that all four hypotheses focus on the temporal domain, while remaining silent about the spatial domain although all of them imply a concurrent spatial change of some sort.

Experiment 1 put the four competing hypotheses to an empirical test. We created a computerized scene of a moving object and allowed viewers to adjust its temporal properties in order to make a given scene appear continuous. Experiment 1 involved a camera jump that did not alter the distance between object and camera. Experiment 2 also considered spatial aspects of continuity by adding a change in camera distance, that is contraction and enlargement were added to the lateral jump of the camera.

EXPERIMENT 1: ADJUSTMENT OF 2D FILM PRESENTATION

This experiment was conducted to assess the accuracy with which observers are able to create a perceptually seamless cut. Observers were presented with a simple dynamic event. In mid-action the camera was displaced. Thus, the second half of the action was shown from a different camera angle. In addition to the change of the camera angle, we introduced a displacement of the moving object, which corresponded to a temporal ellipsis (gap in the film) or a replication (temporal overlap). In terms of the taxonomy used in Table 1, we confronted observers with ellipses and replications and asked them to indicate how to make these transitions appear phenomenally continuous. Initially, the temporal shift was very salient and the moving object appeared to have changed its position immediately after the cut. It was the observer's task to indicate the size and direction of a temporal displacement that could compensate for the perceived shift. In an iterative reviewing of the scene adjusted by the indicated compensatory shift, the observer homed in on a setting that made the sequences look like a straight-match cut without any gap or overlap. We used this method of adjustment to make visible any biases or preferences that observers might have.

Method

Participants

Eight undergraduate and graduate students (five male, three female) at the Massachusetts Institute of Technology volunteered for the study. They ranged in age from 18 to 36 years (average 23.9 years). They were not informed about the purpose of the study until after the experiment.

Apparatus and Stimuli

The display involved a ground plane with several objects scattered upon it. It was a grassy field with trees and two ducks sitting on the low-cut grass. Toward the right-hand side of the scene a large wall was visible. A hovering rocket-shaped blimp came into the scene from the left and moved rightward toward the wall. It crossed the observer's line of sight (0˚) in the middle of the trajectory and continued to fly through the wall (13 m high) and off the right edge of the screen. The center of the blimp was at the simulated eye height of the observer at 1.7 m above the ground. The blimp was 15 m in front of the observer's eye point and covered a distance of approximately 20 m from left to right. In the generic straight-match cut the whole animation lasted 8 s and the cut always occurred after half that time. Depending on the camera angles and on the observer setting, the blimp could leave the screen a little earlier or later. To distract the observer from this fact, the display remained visible until the spacebar was pressed, which indicated that he/she was satisfied with the settings, and the next trial appeared. Observers had control over the blimp's initial position after the cut by indicating where it should be positioned in the next viewing of the sequence.

A 1000 MHz Dell™ PC equipped with a Pentium III™ processor and an NVIDIA G-force2 graphics card were used for the experiment. The displays were generated using a custom made 3D graphics environment (VRUT, which uses Python™ and OpenGL™). A 20" Sony Trinitron™ monitor (38 cm horizontal by 29 cm vertical) presented the animation at a display rate of 72Hz, a refresh rate of 72 Hz (non-interlaced) and a resolution of 1280 × 1024 pixels. The observer's line of sight was centered with respect to the monitor. Viewing distance was 40 cm, which created a visual angle (horizontally) of approximately 50˚. Binocular viewing created a situation similar to sitting in the center of a row toward the front of a movie theater. Note that the viewing distance for "correct viewing" according to the simulation would have been 27 cm. Since in a movie theater, maximally one person can be positioned in the "correct viewing" position, if anything, the deviation from the proper view point in this study should make our results more comparable to actual movie viewing.

Design

As shown in Figure 1, all cuts were chosen such that the Camera Angle Change was symmetric around the midline (straight-ahead view), which is indicated in the figure as 0˚. Thus in the 130˚ condition, the camera was at the leftmost position from the observer for the first half of the trial and at the rightmost position for the second half, or vice versa. Smaller jumps around the midline were created in steps of 20˚. In the no change condition, the camera remained in the 0˚ position. The 0˚ condition was doubled resulting in 16 trials (jumps of 130˚, 110˚, 90˚, 70˚, 50˚, 30˚, 10˚, 0˚ from left-to-right and from right-to-left).

The second factor, Velocity, was fully crossed with Camera Angle Change. That is, all trials were shown at a blimp speed of 1.75 m/s and at 2 m/s. The resulting set of 32 trials was presented to all observers in different random orders. The stationary objects in the scene were fixed in world coordinates at all times. The blimp always moved along the exact same path in the world.

Procedure

The observers sat comfortably in a chair. Their heads were not restrained but they were asked not to move the chair during the experiment and not to lean forward. Observers had five practice trials, and more upon request, to become familiar with the task and the controls. During each trial they saw the blimp-like projectile flying parallel to the ground toward a wall. It was never occluded from view. The entire scene was computer-generated and thus contained less detail than many photographed movie scenes.

Figure 2 illustrates that in addition to, and entirely independent of the change of camera position, the object's position could be altered at the moment of the cut. The left panel illustrates a straight-match cut, the center panel illustrates an ellipsis (the moving object is moved forward in space) and the panel on the right illustrates a replication (the object is moved back in space to a previous position).

Upon press of the space bar, a stimulus appeared with the blimp already in motion. After approximately 4 s, the camera angle changed instantaneously. After the cut, the blimp was initially either placed in a position where it had been up to 2000 ms before the cut (replication), or it was placed up to 2000 ms farther along its trajectory to the right (ellipsis). This post-cut position was determined randomly and led to a noticeable misalignment in most cases. After this rather blatantly unsmooth sequence had been presented, observers had the opportunity to indicate where they would have the blimp appear for the subsequent showing of the sequence. This procedure was repeated until the sequence looked maximally smooth.

To indicate the post-cut position of the object for the next presentation the observer pressed one of four keys, which were assigned to small and large displacements to the left or to the right. The keys were spatially compatible with the displacement from the just-viewed event that they caused.

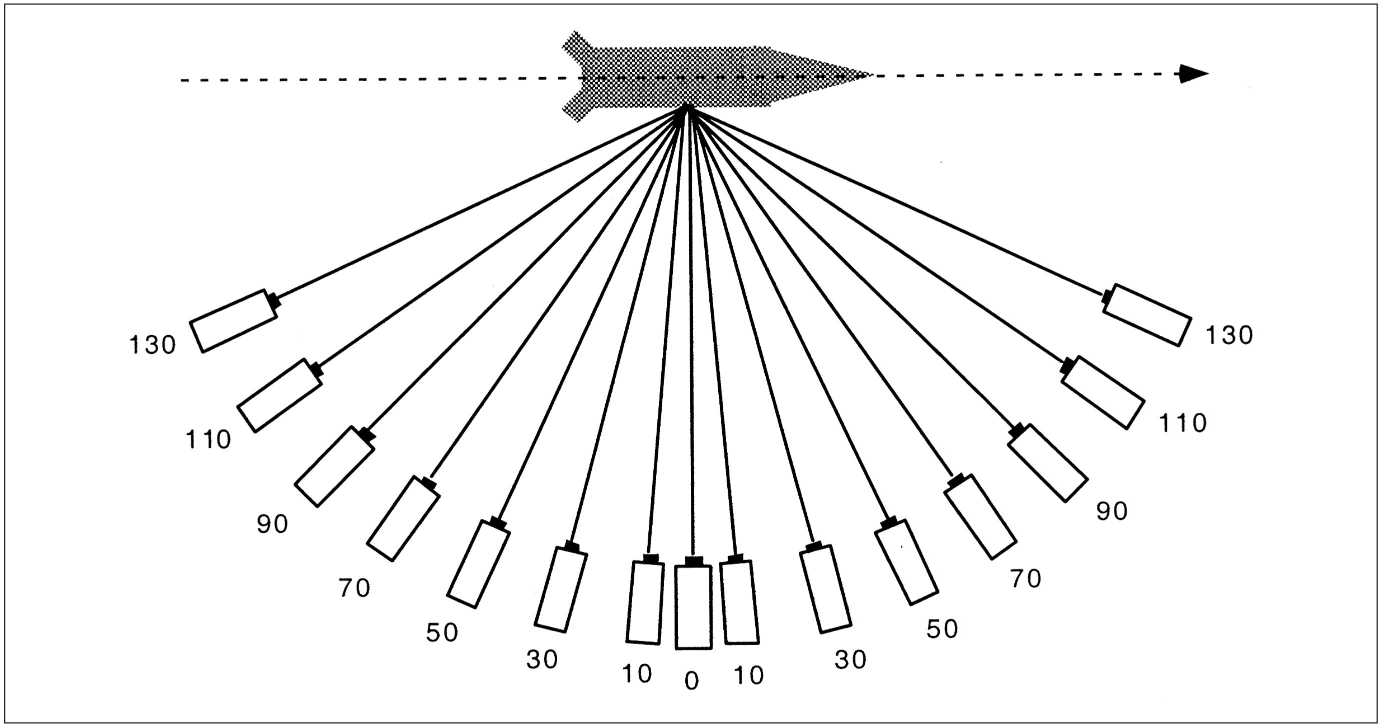

Figure 1. Schematic overview of the camera positions that were used. The camera could either be displaced from left to right or from right to left. The cut was always half way through the animation. Note that all camera angle changes were symmetric around the midline (0). That is, the two camera positions with identical numbers made up one trial. Changes occurred in both directions while the object always moved from left to right. The numbers indicate the angle change in degrees.

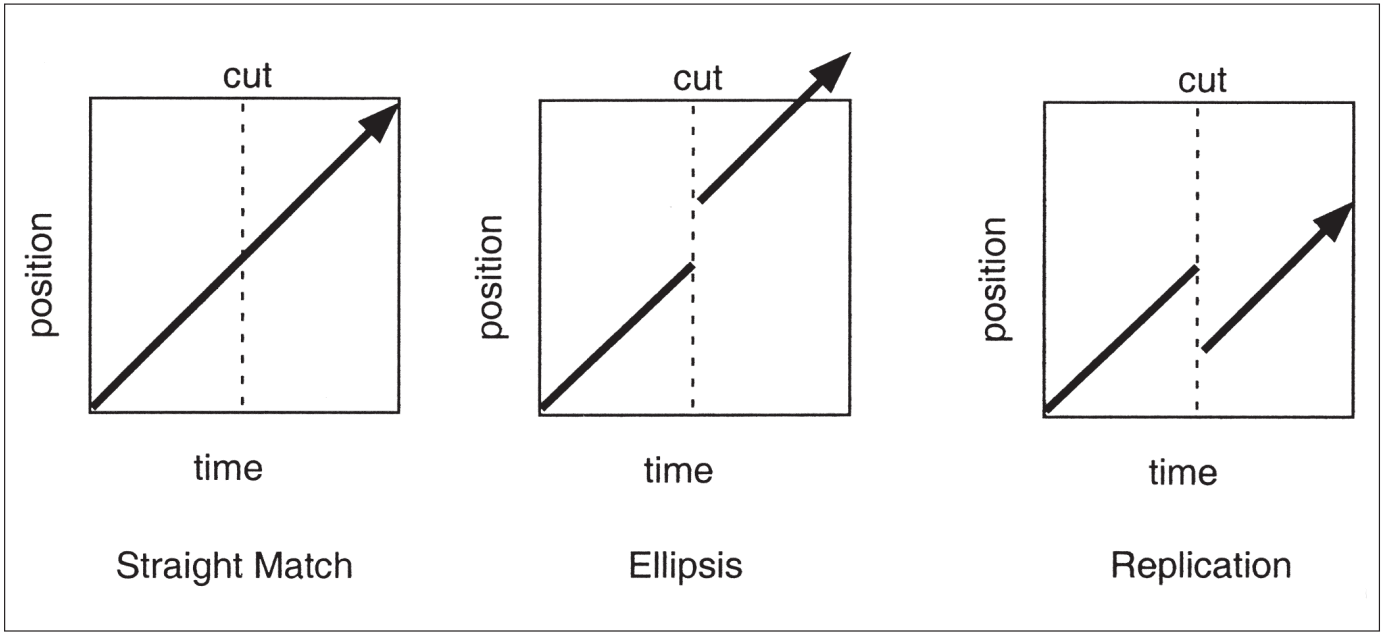

Figure 2. Position-time plots of the event. The left panel illustrates a straight-match cut. At the moment of the cut (vertical line) the camera position changes (not depicted here) while the moving object continues its course seamlessly.The center panel illustrates an ellipsis: At the moment of the cut—in addition to the camera change—the moving object is moved forward in space to a position it would normally have reached later. The panel on the right illustrates a replication: At the moment of the cut, the object is moved back in space to a previous position. Note that after each viewing of the sequence the observers were able to change the position where the object would be after the cut until they subjectively felt the sequence would be a straight match.

The observer was instructed to adjust the displacement such that it resulted in a maximally smooth and subjectively correct animation across the cut. An ideal observer would have positioned the blimp such that its position in the scene was the same immediately before and after the cut. In pilot trials we found it difficult to find a noticeable difference between a straight-match cut and one that deviated less than 200 ms from it (introducing a gap or a time reversal). Hence we determined the smallest control step to be 200 ms. Large displacements effected a change of 800 ms. The key-press caused the same trial to be repeated with the thus changed blimp displacement. The range of possible adjustments was capped at 4000-ms gap or overlap, in which case the screen turned red. Observers also had the option to view the current setting without making changes as many times as they wished. Breaks could be taken by not pressing the space bar after any given trial. On average, the whole experiment lasted about 20 min.

Results

Across all conditions, observers judged the transition to be smoothest when a gap was introduced at the moment of the cut. The size of the gap was on average 182 ms (*SD* = 797 ms). Note that we determined 0 to be the "correct" adjustment. Thus positive and negative deviations from 0 were possible, and accordingly the unsigned average deviation was larger than the signed average. Six of the eight observers consistently showed a clear preference for a gap, one observer had no general bias and one a slight bias in the opposite direction. As visible in Figure 3, observers were basically perfect in the condition where the camera remained unchanged and made errors in all other cases. Despite the rather large standard deviations the data appeared to be normally distributed on visual inspection. A Levene-test for homogeneity of variances in all cases that had a camera displacement indicated that they did not differ significantly from a homogeneous distribution. The box-plot in Figure 4 provides an impression of the rather focused judgments in cases without camera change and the rather variable judgments in all other cases. A two-factor repeated measures Analysis of Variance (ANOVA) was conducted on the signed adjustment errors. That is, a positive value indicated the size of the preferred gap, a negative error indicated the size of the preferred overlap. The first factor, Camera Angle Change, had three levels (camera jump to the left, jump to the right, and no change) and revealed a significant main effect, $F(2, 14) = 4.12$, $p = .039$. Contrasts determined within the same ANOVA revealed that the no-change condition produced smaller errors than the jumps to the left, $F(1, 7) = 6.11$, $p = .043$, and marginally to the right, $F(1, 7) = 4.22$, $p = .079$. Left and right camera jumps did not differ from one another, $F(1, 7) = 0.46$, $p = .52$. The second factor Velocity yielded no significant effects, neither did it interact with Camera Angle Change.

The initial misalignment that was randomly chosen by the computer was highly correlated with the final judgments, $r = .64$, $p < .001$. As expected with proper randomization, over all trials the average initial misalignment was practically

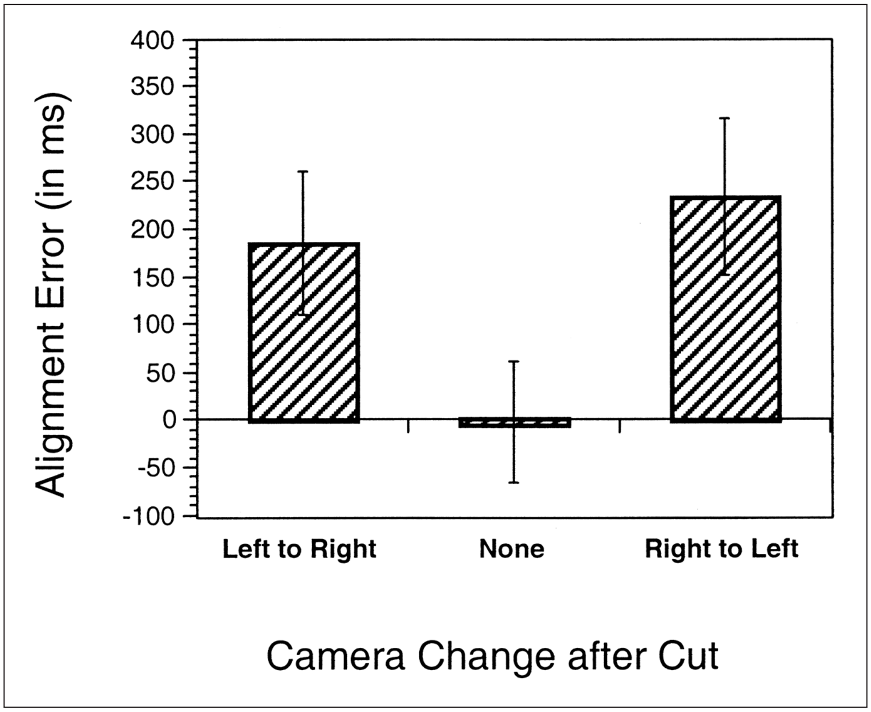

Figure 3. Average judgment errors by type of camera angle change. The position of the moving object in the scene could be adjusted. Positive errors indicate that a gap was introduced, that is the object reappeared too far along its trajectory after the cut. Negative errors would have indicated that the object looked most natural when it backtracked after the cut. Error bars indicate standard errors of the mean.

0 (M = 6 ms, SD = 1181 ms). Thus, the correlation can be explained as a hysteresis effect indicating that there was a huge tolerance to go with the initial presentation. This effect becomes visible in Figure 5. Judgment errors appear to follow the initial setting while being shifted toward the preference for a gap. This interpretation is backed up by the large variances of what was judged to be a smooth transition in all cases but those without camera angle change. See Table 2 for the summary statistics per condition. Many observers reported correspondingly that almost all adjustments looked pretty good. The notable exception was the condition without camera angle change. Those trials produced a clearly noticeable gap whenever they were slightly misaligned, with the possible exception of one observer who also displayed rather large variance in these cases.

A second ANOVA was run to detect a potential effect of the size of the camera angle change and its possible interaction with the direction of change. It had three

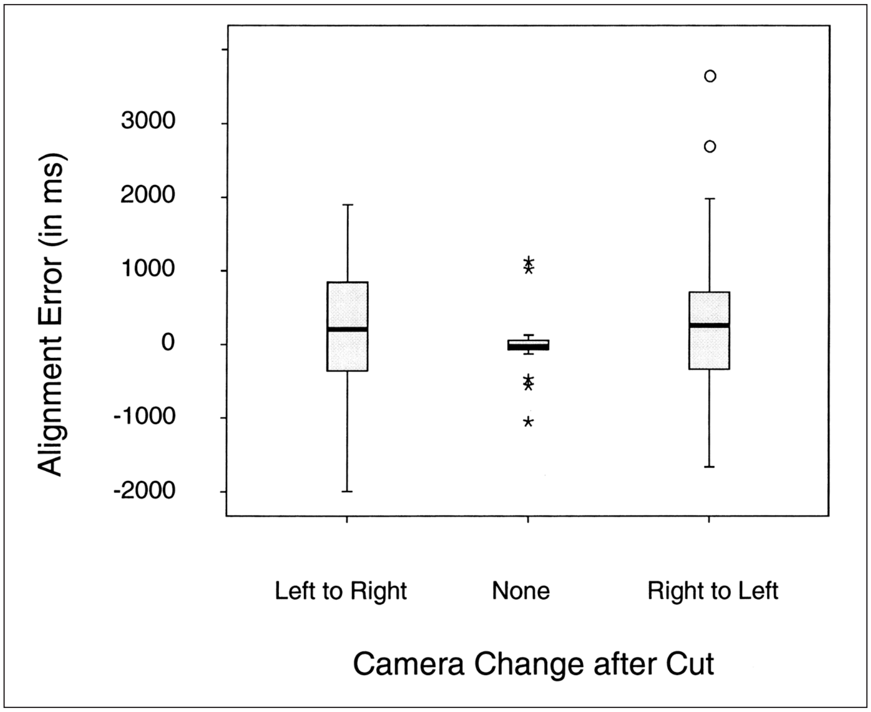

Figure 4. Box plots of the judgment errors obtained in Experiment 1. Trials without camera change varied little and were judged correctly. With camera change data became more variable and moved toward the preference for a gap. The box comprises 50% of the values (2nd and 3rd quartile) in that group. The line in its center indicates the median, numbers outside the box indicate outliers.

repeated factors, Direction of Camera Angle Change (camera jump to the left and to the right), Size of Camera Angle Change (10°, 30°, 50°, 70°, 90°, 110°, 130°), and Velocity (1.75 m/s and 2 m/s). The trials without camera angle change were omitted from this analysis. Direction and Size of Camera Angle Change had no effect, $F(1, 7) = .46$ and $F(6, 42) = 1.38$, respectively. A main effect of velocity failed to reach significance, $F(1, 7) = 4.87$, $p = .063$. Faster trials tended to be more accurate, that is, the gap that was found to make fast trials look smooth was somewhat smaller than for slow trials. None of the interactions approached significance.

Discussion

Contrary to Dmytryk's (1984) and Anderson's (1996) continuity editing rule, our observers did not prefer overlapping action. They preferred a temporal gap equivalent to leaving 4 frames on the cutting floor of a movie presented at 24 frames per second.

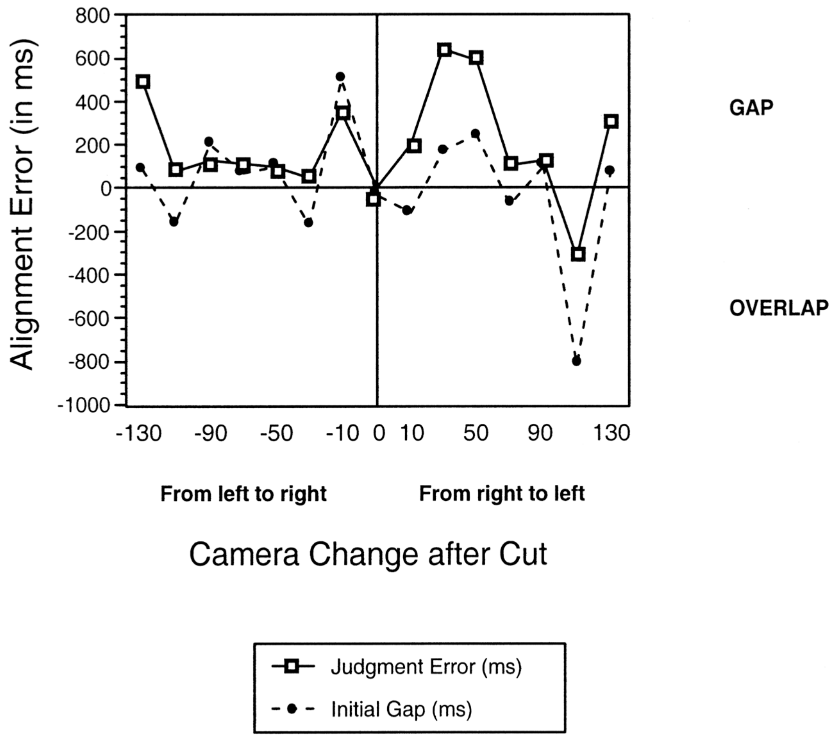

Figure 5. Average judgment error compared to the randomly chosen initial displacement for all camera angle changes separately. The judgment errors follow, to some extent, the initial random setting, which indicates the large tolerance that observers have for misalignment.

Table 2. Summary Statistics of Alignment Settings by Condition

Camera Angle Change	Average Settings (ms)	Variance	Minimum	Maximum
Left to Right	185	654	–1,990	1,903
None	–3	131	–1,051	1,288
Right to Left	233	756	–1,665	3,646

This corresponds remarkably well with the ellipsis hypothesis based on Mehnert's (1963) recommendations. Surprisingly, this bias did not change with the size of the camera angle change. As long as there was a change at all, whether it was as small as 10° or as large as 130°, the same temporal gap was judged to produce the smoothest transition. This preference for a gap only surfaced when averaging the data because there was a remarkable tolerance for temporal mismatch. Observers tended to adhere to the initial setting although it was randomly assigned. This hysteresis effect, the fact that the initial object position after the cut mattered, suggests that observers were not very sensitive to the spatiotemporal discontinuity that is introduced by a camera angle change. This is consistent with the plasticity of human motion perception inasmuch as motion is always integrated over larger time periods. For instance, sudden onsets are typically perceived as extended over time and constant velocity is not always perceived as such (Gottsdanker, Frick, & Lockard, 1961; Runeson, 1974). Our findings are also consistent with the so-called phenomenon of change blindness (Simons, 2000; Simons & Chabris, 1999). Observers fail to notice changes that are made to a scene while they move their eyes or while some other disruption occurs. However, this effect disappears with attention, and we can be reasonably sure that our observers attended to the moving blimp.

EXPERIMENT 2: CHANGING CAMERA DISTANCE ACROSS A CUT

In Experiment 1, we held camera distance between observer and object constant. The lateral translations which were introduced represent a rather restricted observer displacement. Thus, in Experiment 2 we added more substantial spatial discontinuities and simulated an approaching or receding observer by changing the camera distance from the observer at the exact time of the lateral camera jump. As before, experienced directors and film people seem outspoken but inconsistent about how to change the timing for such contraction and enlargement shots, which cover different spatial scopes of the scene before and after the cut. In order to corroborate this point, one of the authors (HK) informally interviewed three cutters (CA CP AY) and five cameramen (FF MH MK KL MS) who were well practiced in film editing. The interviews were conducted at the Göttingen Institute for the Scientific Film (IWF; now IWF Knowledge and Media). The interviewees seemed to agree (with the exception of MH) that in general and regardless of spatial considerations a smooth transition can be achieved by dropping a few frames (ellipsis). One camera man (MH) was outspoken about the necessity to remove a few frames after the cut (ellipsis) in the case of a spatial contraction while overlapping (replication) a few frames in the opposite case of spatial enlargement. The predictions according to our spatio-temporal taxonomy made by the Göttingen experts as well as by some of the cited authors are summarized in Table 3.

Table 3. Expert Predictions of Phenomenal Continuity Across Mid-Action Cuts, using the Taxonomy of Table 1. Vertical Names Indicate Those Experts Who Suggest the Respective Continuity Edit Regardless of Concurrent Spatial Changes. Horizontal Expert Names Indicate Cut Suggestions for a Given Spatial Change

<table>
<tr><th></th><th></th><th colspan="3">Temporal</th></tr>
<tr><th></th><th></th><th>Replication</th><th>Continuation</th><th>Ellipsis</th></tr>
<tr><td rowspan="3">SPATIAL</td><td>Enlargement</td><td>Madsen
IWF: MH</td><td rowspan="3">Reisz & Millar; IWF;FF MH CP MS AY</td><td rowspan="2">Mehnert; IWF: CA FF MK KL CP AY</td></tr>
<tr><td>Equidistance</td><td rowspan="2">Anderson; DM YTRIK; IWF:FF MK MS</td></tr>
<tr><td>Contraction</td><td>Madsen
IWF: MH</td></tr>
</table>

The only documented editing recommendation in the direction of MH's recommendation that we could find in the existing literature was put forth by Madsen (1973): "If the cut is being made from a larger scene size to a smaller [contraction, *added by authors*], such as a long shot to a close-up, several frames of movement at the head of the second scene are deleted . . . because the shock value of an abrupt move closer carries with it the cinematic illusion of edited movement. . . . Conversely, when a cut is made from a smaller scene size to a larger, such as a close-up to a full shot, several frames at the head of the second scene overlap [enlargement, *added by authors*] the tail action of the first. The edited action briefly duplicates the movement at the head of the second scene because of the disorienting effect of moving suddenly from a smaller to a larger scene size" (Madsen, 1973, p. 90). In other words, Madsen's observations predict that observers prefer a temporal gap for a cut involving a contraction, while temporal overlap should make transitions along with enlargements appear most natural.

We designed this second experiment to test Madsen's (1973) predictions. Again, a moving blimp was simulated on a computer monitor and observers had the opportunity to adjust the blimp's position after the cut for the next viewing of the sequence. A contraction, no change of scene size, or an enlargement could occur at the moment of the cut (Camera Distance Change). Note, that the Camera Distance Change was added to the translational displacement of the camera (see Figure 1) in order to make the experiment directly comparable to first one.

Method

Participants

Nine undergraduate and graduate students (four male, five female) at the Massachusetts Institute of Technology volunteered for the study. They ranged in age from 18 to 29 years (average 20.3 years). They were not informed about the purpose of the study until after the experiment. None of them had participated in Experiment 1.

Apparatus and Stimuli

The same grassy ground plane with several scattered objects was computer-generated as in Experiment 1. As before, toward the right-hand side of the scene a large wall was visible. A hovering blimp-shaped rocket moved toward it from the observer's left to the right. The motion of the blimp was perpendicular to the observer's line of sight at the 0°-point where the blimp crossed the line of sight. At this point the blimp was maximally 33 m from the observer while its distance to the target wall was 12 m. The same computer and display parameters were used as in Experiment 1.

Design and Procedure

Three initial camera distances were chosen such that the object was at 33, 25, and 17 m from the observer when crossing the line of sight. After the cut, paired with each of these initial distances, was a condition of equidistance, a contraction, or an enlargement, such that all possible scenarios were filled. For instance, an initial distance of 33 m only allows a contraction by 8 m or by 16 m. The initial distance of 25 m allows for a contraction or an enlargement by 8 m each; and so forth. This method yielded 9 distinct events which we grouped into five categories:

(1) non-changes at 33, 25, and 17 m;
(2) small enlargements of +8 m (from 25 to 33 m, or from 17 to 25 m);

(3) large enlargements of +16 m (from 17 to 33 m);
(4) small contractions of –8 m (from 33 to 25 m, or from 25 to 17 m);
(5) large contractions of –16 m (from 33 to 17 m).

Object speed was always 1.75 m/s. Camera angles were either held constant, with the line of sight perpendicular to the motion trajectory of the blimp (compare the 0˚ condition in Figure 1), or the camera was at +45˚ before the cut and at –45˚ after the cut. Thus, Camera Angle Change had two levels, no change and a 90˚ change from right to left, which necessarily included a lateral displacement of the camera. These values were chosen because they represent a symmetric camera angle at about the average angle used in Experiment 1. All stimuli were presented with two different backgrounds (many other objects vs. target only). The resulting 36 trials (9 camera distance changes, 2 camera angle changes, 2 backgrounds) were presented at different random orders for each participant.

Results

A three-factor (Camera Distance Change, Camera Angle Change, Background) repeated measures ANOVA was run on the gap/overlap size that observers introduced into the scene. The variable Camera Distance Change was grouped into five categories as indicated above. The main effect was significant, $F(4, 32) = 9.15, p < .001$. Both enlargements (the smaller step of 8 m as well as the larger step of 16 m) were significantly different from the no-change condition, $F(1, 8) = 11.18, p = .01$ and $F(1, 8) = 21.61, p = .002$, respectively. The contractions did not differ significantly from no-change trials. The minimalist and elaborate backgrounds did not differ from one another. The camera angle change after the cut in addition to the given distance change, tended to produce larger gaps than the cases in which only camera distance was changed, $F(1, 8) = 4.37, p < .07$. It is visible in Figures 6 and 7 that the enlargement trials contributed to this effect, which failed to reach significance. No other trends or significant interactions were found.

The average gap of .33 m that was produced for trials containing a camera angle change (and the associated lateral camera jump) corresponded to a time error of 187 ms. The direction and magnitude of the effect was comparable to that obtained in Experiment 1. Results were consistent among observers. For instance, eight observers preferred a gap for the enlargement trials that covered the 16 m rearward camera displacement. The produced gaps ranged in size from .27 to 1.09 m (corresponding to a temporal range from 154 to 623 ms). Only one observer preferred a small overlap of –.1 m.

Discussion

Enlargement of scene size during a cut produced a strong preference for a gap in the action, or in other words, for a jump forward of the moving object along its trajectory. Contraction of scene size produced a smaller gap, or even an overlap

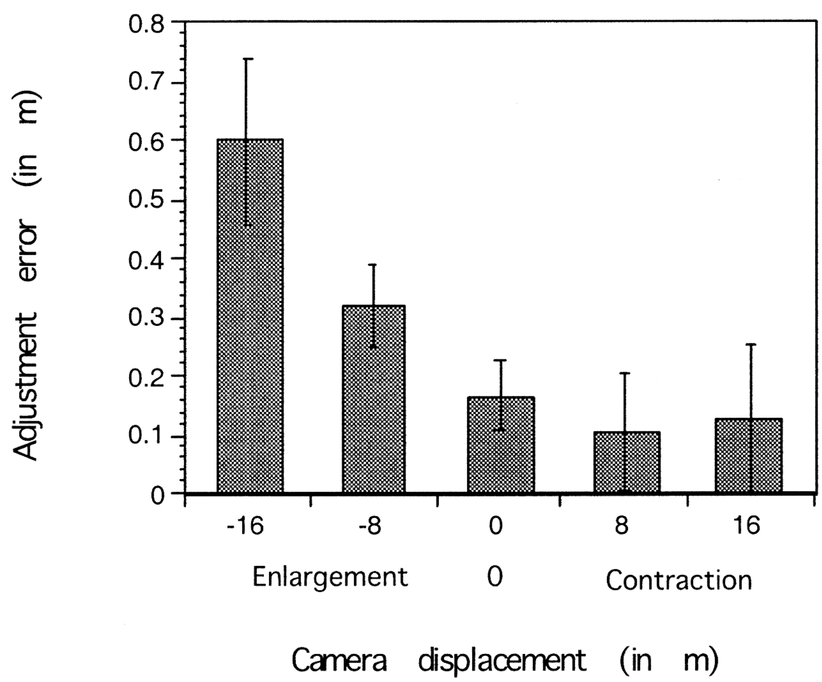

Figure 6. Adjustment errors averaged across all camera angle changes for the two cases of spatial discontinuity. Positive numbers indicate that, on average observers preferred gaps in all cases. The largest gaps were produced in the case of enlargements, that is, when the camera was close-up before the cut and far from the object (long shot) after the cut. Error bars indicate standard errors of the mean.

when the camera remained on its initial axis. From the control condition without a camera distance change (and hence without the associated change of scene size) and without a camera angle change, it is clear that observers were very accurate adjusting the initial random gap to a value close to perfection. For this actually continuous condition, the average error expressed in deviation along the blimp's trajectory was only 0.017 m. The effect of Camera Angle Change, which was very salient in Experiment 1, was almost masked by the Camera Distance effect. The absence of an interaction between the two speaks in favor of this interpretation.

We found no support for Madsen's (1973) observations. To the contrary, our observers preferred a gap and not overlap in the case of enlargement across a cut. In case of contraction, the preferred gap became considerably smaller, and in some

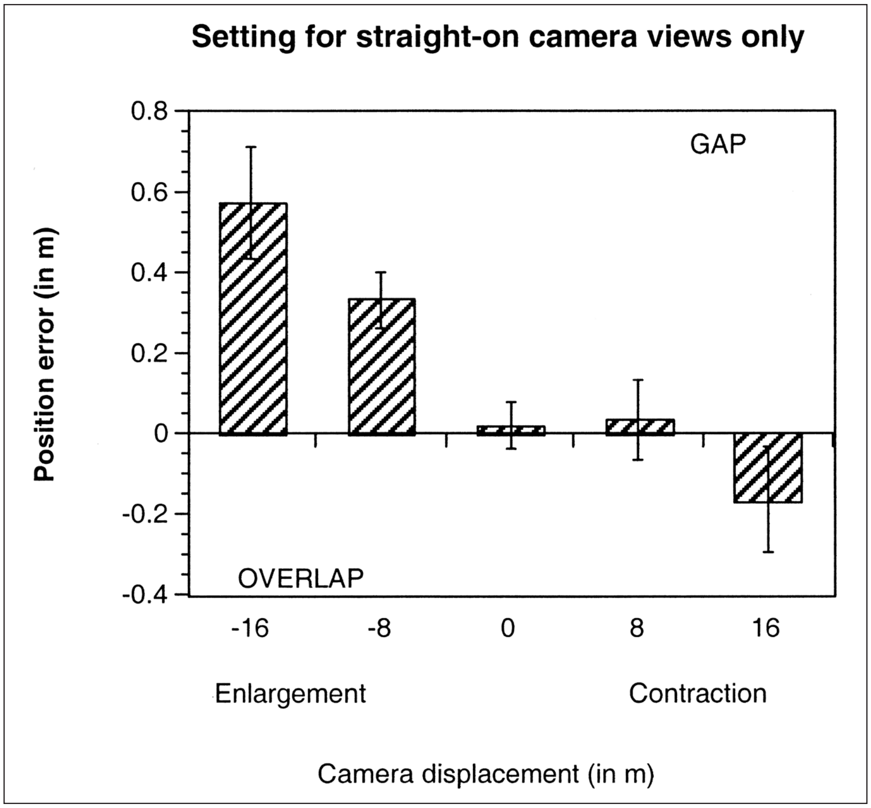

Figure 7. Adjustment errors for fixed camera positions only and by spatial discontinuity. Removing the lateral camera position changes from the data reveals that gaps are preferred for enlargements while overlap is preferred for contractions. Error bars indicate standard errors of the mean.

large contractions even turned into an overlap. Thus, the intuition of the Göttingen film experts (MH excepted) proved rather accurate. The data collected in Experiment 2 also speak against the cut hypotheses suggested by Reisz and Millar (1968) as well as against Dmytryk's (1984) rules. Mehnert's (1963) ellipsis hypothesis, on the other hand, is primarily supported. It was generally true, that observers preferred an ellipsis, a gap in the action whenever the cut included a translational camera jump. The additional change of scene size modulated the size of the preferred gap: a contraction reduced its size while an enlargement increased it up to 350 ms.

GENERAL DISCUSSION

Visual perception in everyday conditions is largely continuous, notwithstanding brief interruptions, such as during eye blinks, eye movements, or when an object moves behind a lattice fence or some other occluder. Continuity editing in film, on the other hand, profusely orchestrates large jumps in space and time to fit large travels and entire lives into a feature-length film. Surprisingly, film experts, such as film critics and directors, have suggested rather contradictory recipes for how phenomenally smooth transitions across cuts are to be accomplished. We have discerned four distinct hypotheses. The first three arose within the domain of filmmaking, the fourth within perceptual psychology. The straight-match hypothesis (Reisz & Millar, 1968) posits that a cut will appear discontinuous unless the new camera picks up the world action at exactly the point where the first camera has left off. The ellipsis hypothesis (Mehnert, 1963) proposes that an ellipsis is required to reach maximal perceived continuity. The replication hypothesis (Anderson, 1996; Dmytryk, 1984) states that a replication is required for optimal phenomenal continuity. Finally, the psychological non-discrimination hypothesis (Levin & Simons, 2000) argues that spatio-temporal discontinuities are simply not detected by the observer, and therefore straight match, ellipsis, and replication should all appear continuous. The non-discrimination hypothesis is based on findings that human observers are often strikingly incompetent at detecting change; they even fail to detect when their conversation partner is switched on them in mid-conversation. Our detection of changes that happen while perception is interrupted is extremely poor.

Clearly, the non-discrimination hypothesis has to be rejected on the basis of our findings. Instead of choosing arbitrary gaps or overlaps when adjusting the film cut across a camera jump, our observers universally preferred a gap. They were able to discriminate, albeit with a strong bias in the direction of the initial setting. The straight-match hypothesis as well as the replication hypothesis are also ruled out by our data. The empirical results consistently obtained in both experiments speak in favor of the ellipsis-hypothesis.

As Mehnert (1963) has suggested the ellipsis technique, let us look at his explanation of it. In his book, rule 32 specifies match cut editing as follows: “Each change in camera position . . . produces a psychological temporal loss, as if time had passed during the transition despite this not being the case. Therefore it is permissible to shorten part of a continuously ongoing action after the cut” (translation by the authors). Thus, interruption causes a temporal loss along the psychological time line that has to be matched by the film. Prima facie, this explanation does not seem more convincing than the arguments that were used to justify the competing hypotheses, which have not withstood empirical testing. However, if we take a closer look at the experimental literature involved with motion processing (for an introduction, see Hochberg & Brooks, 1978), we find a number of related hypotheses.

We will briefly entertain explanations derived from two concepts that have been used in the investigation of motion perception around temporal and spatial transients. Transients or sudden onsets or offsets of motion seem to receive special treatment by the visual system. For instance, whenever an object abruptly starts to move, its motion is hardly ever perceived as such (Runeson, 1974), but it is integrated and equalized to be compatible with the speed of our actions. That is, when an object starts to move instantaneously at a given constant speed, it is nonetheless perceived to gradually accelerate toward this speed.

The first concept is that eye movements may create temporal loss. During eye movements, motion processing is impaired, and a film cut is likely to induce orienting eye movements (for a detailed account see d'Ydewalle, Desmet, & Van Rensbergen, 1998; d'Ydewalle & Vanderbeeken, 1990). It is, however, unclear whether the re-orienting eye movement should not rather require some time and make temporal gain more appropriate than temporal loss.

The second concept has to do with the Fröhlich (1923) effect. When a moving object enters a window or a screen, it is perceived to have appeared farther along its trajectory than it actually has. In other words, perception suffers from a temporal loss in this case. More recently, Kerzel and Müsseler (2002) have attempted to explain the effect by the necessity to reset processes of spatio-temporal integration whenever an abrupt change in the visual field occurs. One particular aspect of spatiotemporal integration has been investigated at length by Jennifer Freyd and colleagues. These researchers argue that movements in the world are mentally represented in a continuous fashion. When asked to judge at which position a given object has disappeared, they do not recall the visual perception from a few seconds ago, but rather access their ongoing mental representation. Consequently, a suddenly disappearing object is judged to have vanished farther along its motion path than it actually did (Freyd, 1987; Freyd & Finke, 1984; Freyd & Pantzer, 1995; Hubbard, 2005).

To apply the concept of representational momentum to our findings, we would have to assume that an anticipatory representation is produced in parallel to our perception. The anticipatory representation normally gives us a little lead time to prepare actions. A cut causes the new visual scene to be synchronized with the representational trace rather than with the perception. At present this dualistic notion of parallel representation and perception remains speculative. Finally, as clearly as observers favor the ellipsis, we are left with the puzzle that neither of the three above concepts is able to explain why the preferred size of the ellipsis increases when an enlargement is added to the change of the camera axis.

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