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Taylor, G and Herbert, JS

<http://dx.doi.org/10.1111/sjop.12002>

Title	Eye tracking infants : investigating the role of attention during learning on recognition memory
Authors	Taylor, G and Herbert, JS
Publication title	Scandinavian Journal of Psychology
Publisher	Wiley
Type	Article
USIR URL	This version is available at: http://usir.salford.ac.uk/id/eprint/40283/
Published Date	2013

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Eye tracking infants: Investigating the role of attention during learning on recognition
memory

Gemma Taylor and Jane S. Herbert

Department of Psychology

University of Sheffield

Authors' Notes

This research was supported by an ESRC studentship (ES/1018786/1) to the first author. The authors would like to thank all the infants and parents who participated in this project.

Corresponding author: Dr. Jane S. Herbert, Department of Psychology, University of Sheffield, Sheffield S10 2TN, United Kingdom. Phone: +44 (0) 114 222 6512, Fax: +44 (0) 114 276 6515, email: j.s.herbert@sheffield.ac.uk

Abstract

In the present study, eye tracker methodology was used to explore whether there were age-related changes in the focus of infant attention during a learning event and subsequent recognition memory for event features. Six- and 9-month old infants watched a video of an adult demonstrating a sequence of actions with an object while visual attention was recorded using an eye tracker. At both ages, attention was focused primarily on the object and person, with the background attended to for approximately 12% of their viewing time. Recognition memory for the person, object and background from the video was assessed immediately using a Visual Paired Comparison procedure. Despite focusing on the central features while watching the target video, infants showed only limited evidence of recognition memory for the individual components of the event. Taken together, these findings suggest that age-related changes in memory performance during the first year of life are unlikely to be the result of age-related changes in attentional focus during encoding.

Introduction

Memory abilities develop rapidly during the first year of life. Across paradigms, age-related changes have been observed in the duration over which infants can retain memories and in their ability to express their memories in new situations (for review, see Hayne, 2004; Jones & Herbert, 2006). At any given age, events that happen at the time of encoding can impact on the exact duration over which a memory can be retained. For example, providing infants with additional encoding time (Barr, Dowden, & Hayne, 1996), the opportunity to immediately reproduce target actions (Hayne, Barr, & Herbert, 2003), language cues (Bauer, Wenner, Dropik, & Wewerka, 2000; Hayne & Herbert, 2004), or allowing an association to be formed between the target event and another, longer remembered, event (Barr, Vieira, & Rovee-Collier, 2001; 2002) can protract the duration of retention for the target actions in an imitation task. Similarly, the opportunity to immediately reproduce the target actions (Hayne et al., 2003; Learmonth, Lamberth, & Rovee-Collier, 2004, 2005), and the provision of language cues at encoding and retrieval (Herbert & Hayne, 2000; Herbert, 2011), can facilitate infants' ability to retrieve their memories in situations that are similar, but not identical, to those experienced at encoding.

Whilst researchers are developing a clearer picture of the factors that impact on infants' ability to retain and express their memories, considerably less is known about how infants respond to the events happening during the learning phase itself. Studies of retention have revealed that, in general, older infants require a shorter period of learning than younger infants (e.g., Hill, Borovsky, & Rovee-Collier, 1988; Barr et al., 1996; Rose, 1983). For example, between 6- and 12-months, the encoding time required for memory to persist over a particular retention interval approximately halves (e.g., Barr et al., 1996; Rose, 1983). However, it is unclear why encoding rates increase with age. Younger infants may encode

information in the same way as older infants, but simply be doing so at a slower rate. Alternatively they may be attending to different aspects of the learning event (for a similar argument see Jones & Herbert, 2006). The present research uses eye tracking methodology to examine how infants attend to a learning experience. The overarching goal of this research is to determine the extent to which age-related differences in attentional focus during learning might account, at least in part, for developmental changes in later memory.

Eye tracker methodology is ideally suited to studying early learning and memory because, like other measures of visual attention (e.g., Fagan 1970), infants simply need to gaze at scenes or objects (usually images on a screen) rather than produce a motoric behaviour or verbal response (for a review of eye tracker methodology in infancy research, see Gredebäck, Johnson, & von Hofsten, 2010). Knowing how images and dynamic events are scanned by infants provides valuable information about what has been perceived and is, therefore, potentially available for encoding and subsequent recall. Initial eye tracker studies have revealed that, compared to older infants, younger infants are more easily distractible and may distribute their attention more broadly when watching a complex event. For example, when presented simultaneously with a target and a distracter in different locations on the screen, 3-month old infants produce a greater proportion of looks to the distracter compared to 6- and 9-month old infants (Amso & Johnson, 2008). In addition, three-month old infants also show widely distributed scanning patterns while viewing short cartoon clips compared to 6-month old infants, whose scanning patterns were driven by perceptual salience, and 9-month old infants, whose scanning patterns were focused toward faces (Frank, Vul, & Johnson, 2009).

Developmental changes in scanning patterns may also reveal information about changes in the way infants understand or interpret the actions they are observing. In a recent study, Gredebäck, Stasiewicz, Falck-Ytter, Rosander, and von Hofsten (2009) tracked the gaze shifts of 10- and 14-month old infants when presented with videos of different manual actions.

Infants saw an adult reach for and displace a series of objects (displacement) or place them into a container (containment), or just move his fist back and forth across the table without any objects (control). Regardless of the actions or goals, 10-month old infants exhibited reactive gaze shifts. That is, they followed the movement of the arm without anticipatory gaze shifts towards the goal of the action. In contrast, 14-month olds were predictive in their gaze shifts, fixating on the goal before the hand reached the object (in the displacement condition) or the object reached the container (in the containment condition). Thus, changes in scanning patterns across age could reflect infants increasing understanding about the goals of actions.

Whilst these findings indicate that there may be differences in the way that infants of different ages visually attend to an event, it remains to be determined whether different gaze patterns result in different learning and memory outcomes. This issue has been considered in older children, in a study designed to determine whether differences in visual attention might account for the unique pattern of imitation performance exhibited by children with autism. Vivanti, Nadig, Ozonoff, and Rogers (2008) tracked the visual attention of 8- to 15-year olds as they watched videos of an adult demonstrating a series of actions, and then tested the children's behavioural recall of the actions they had observed. Overall, the visual attention patterns were similar across the healthy and autistic children in terms of the amount of attention paid to the action region of the video. In addition, both groups showed an overall increase in attention to the face region in response to the demonstration of non-meaningful gestures, although the autistic children spent significantly less time looking at the face than the healthy children. For the autistic children, there was a correlation between attention to the action region and the precision of their imitation of non-meaningful gestures. Thus, this research suggests a link between visual attention during learning and what has been learnt. The potential importance of attention during the encoding phase for subsequent learning and memory at younger ages in typical development remains to be determined.

The purpose of the present study is to examine the focus of infant attention during a learning event and explore whether subsequent recognition memory for event features change across age. To do this, 6- and 9-month old infants in the experimental condition watched a video demonstration of a puppet imitation task that is well established in the study of infant memory (for review, see Hayne, 2004) and has been used in imitation from television studies with infants as young as 6-months (e.g., Barr, Muentener, & Garcia, 2007). We hypothesised that visual attention to event components would differ between the age groups to reflect their progressing ability to express their memories in new situations. For example, attending more to the central stimulus (the puppet), rather than the person demonstrating the actions or the background details, may enable this aspect of the event to be a more effective cue for later memory retrieval than the person or background. Given that older infants have more flexible memory retrieval across changes in contextual and social cues (for review, see Hayne, 2004; Jones & Herbert, 2006), we predicted that older infants would attend more to the central stimulus at encoding. This proposal is also in line with the findings of Vivanti et al., (2008) in which older children primarily attended to the action area when the actions being demonstrated were meaningful actions on objects rather than non-meaningful gestures.

Immediately after viewing the video presentation, infants' recognition memory for the individual event components from the video (person, puppet, background) was assessed in the present study using a visual recognition procedure, the Visual Paired Comparison (VPC) task. In the VPC task, recognition for a previously seen item is assessed by presenting infants with the now familiar item along with a "novel" item (for review, see Pascalis & de Haan, 2001). We hypothesised that both age groups would show recognition memory for each event component, consistent with previous research with the puppet task demonstrating that memory retrieval is only observed at these ages when there are no changes in the person, stimulus, or background between encoding and retrieval (e.g., Hayne, MacDonald, & Barr, 1997; Hayne, Boniface, & Barr, 2000; Learmonth et al., 2004, 2005).

Method

Participants

Participants were 26 6-month old infants (14 males and 12 females) and 26 9-month old infants (12 males and 14 females). All infants were typically-developing and were tested within 10 days of their 6- and 9-month birthday. Infants were randomly assigned to the experimental (n=32: 16 6-month olds, 16 9-month olds) or the control condition (n=20: 10 6-month olds, 10 9-month olds). An additional 32 infants (38% attrition rate) were excluded due to: poor calibration accuracy (n=5, 6%), looking at the video for less than 10 seconds (n=11, 13%) and exhibiting positional biases on more than one of the recognition tests (n=16, 19%). This attrition rate is consistent with studies employing eye tracking (e.g., 31% Amso & Johnson, 2008; 48 % Frank, Vul & Johnson, 2009) with these ages. Our attrition rate is higher than previous studies employing VPC procedures (exclusion for side bias 6.5% Richmond & Nelson, 2009; 8% Jones, Pascalis, Eacott & Herbert, 2011), however this can be attributed to the fact that we used three recognition tests compared to just one as is typical in VPC studies.

Design

Infants were assigned to one of two groups, an experimental or control group. Infants in the experimental group watched a video of a learning event, during which visual attention was measured. This was followed by a visual recognition test to assess memory for event components which were paired with related but unfamiliar images. The purpose of the control group was to determine whether infants exhibited a spontaneous preference for the images shown during the recognition test when both were novel. Infants in the control therefore watched a video that was unrelated to the subsequent recognition test.

Apparatus

An SMI iView X (RED III) remote eye-tracking system was used to track infant visual fixations. The direction of the infant's gaze was recorded by a small infra-red camera which used the corneal reflex, sampled at a rate of 50Hz with a gaze position accuracy of 0.5 - 1 degree. The camera was situated directly below the centre of a 56cm flat panel monitor. Stimulus presentation and data output were accomplished using I-ViewX and Begaze software (SensoMotoric Instruments GmbH, Germany).

Materials

Two videos were created for the current experiment. The experimental video was 49 seconds in duration, and showed a female adult demonstrating a series of target actions with a grey rabbit hand puppet (see Figure 1; for further detail about the puppet stimulus, see Barr et al., 1996). The model waved hello directly into the camera, and then demonstrated a three-step sequence of actions with the puppet: taking off the puppet's mitten, shaking the mitten elaborately three times, and replacing the mitten. The target actions were repeated three times in succession, after which the experimenter waved goodbye. The control video was 40 seconds in duration and showed a different model demonstrating a sequence of actions with an unrelated stimulus (a rattle stimulus, see Herbert & Hayne, 2000). Both videos were presented without sound, and were repeated twice to ensure that infants had been shown 6 demonstrations of the target actions (see Barr et al., 1996). Each video was presented in the centre of the screen at a size of approximately 20.8° (width) x 13.3° (height) visual angle on a uniform grey background. The overall screen size was 43cm (width) x 27cm (height), thus the video filled approximately half the screen.

The stimuli for the recognition memory test were digital photographs of the puppet (16.1° X 17.1°), the demonstrator's face (17.5° X 14.7°) and the room background (17.0° X 11.7°) which all featured in the experimental video (see Figure 1). A digital photograph of each item was prepared in Microsoft PowerPoint using Adobe Photoshop to adjust for

individual size and cropped so that there was no extraneous information available. Each image was then paired with a related but unfamiliar image for the recognition test (e.g., the grey rabbit puppet was paired with a grey mouse puppet). The two images were not matched for overall similarity, as the primary measure was attention to each image, not the infant's ability to discriminate between the images.

Procedure

Infants were seated on their caregiver's lap, approximately 60cm from the computer screen. The caregiver was asked to refrain from behaviourally or verbally directing their infant's attention. The experimenter tracked the infant's head movements on the eye-tracker camera from behind a black screen. Once a stable image of the infant's left eye had been obtained, the experimenter proceeded to the calibration procedure. To calibrate the location of the infant's gaze, an attention-getter (an animated fish, 2.9° X 2.4°) was shown individually at five points on the screen: one at each of the corners and one in the middle of the screen. A manual calibration procedure was used; the experimenter accepted each calibration point when a stable diamond appeared around the cross representing the calibration point. Calibration accuracy was checked and repeated as necessary.

Visual attention during learning: Depending on group assignment, infants were presented with either the experimental or control video immediately after the calibration. After the video had been presented for the first time, the accuracy of the calibration was confirmed by presenting an attention-getter (an animated "Elmo" character, 2.4° X 2.9°) in the five calibration locations around the screen. Once the calibration accuracy was confirmed, the same experimental or control video was shown for a second time.

Visual recognition test: Immediately after the second presentation of the video, infants' were presented with three visual recognition tests for items seen on the video: puppet, person, background. Each stimulus pairing was presented twice in succession for 5 seconds, with the

lateral position of the images reversed on the second trial to control for potential side biases. The order in which the three stimulus types were presented was counterbalanced across participants.

Data Analysis

Infant visual attention was analysed in BeGaze. Fixations are defined in the literature as anything from 50-250ms (for discussion, see Holmqvist, Nyström, Andersson, Dewhurst, Jarodzka & Van de Weijer, 2011). Fixations to the dynamic video stimulus in this study were defined as a minimum duration of 80ms and a maximum dispersion of 100 pixels. Data between fixations are defined as saccades. Blink data less than 70ms was discarded, while missing data above this value was recorded in terms of start time and end time for each stimulus.

To investigate infant visual attention to features of the video, three Areas of Interest (AOI) were defined on a screenshot of the video (see Figure 2); the puppet (80,951 square pixels which included the puppet's face and torso), person (80,951 square pixels which included the demonstrator's face and torso) and background (184,800 square pixels covering the remainder of the video presentation). Note that, by definition, the size of the background is considerably larger than the person and the puppet, therefore the background AOI is over twice as large as the other AOIs. Although the video contained some movement, the person and the puppet remained in relatively the same position throughout, so static AOIs were suitable to capture their location. Computer generated data provided the Dwell time, the sum of all saccades and fixations for each AOI.

Results

Visual attention during learning

Initial analyses revealed that the overall amount of time infants looked at the screen during the experimental video did not differ as a function of age (6-months: $M=34.9$ s, $SD=17.4$; 9-months: $M=37.7$ s, $SD=18.9$; $t(30) = -.439$, $p=.66$). To determine whether looking to the specific regions of the video differed as a function of age, a two-way (mixed) ANOVA was then applied to the gaze duration data from the 3 AOIs from the experimental groups. There was no main effect of age on looking time, $F(1, 30) = .054$, $p=.82$ and no interaction effect between age and AOI, $F(2,60) = .345$, $p=.71$. However, visual attention did differ according to AOI, $F(2,60)=4.40$, $p=.02$. Both age groups spent significantly longer looking at the puppet ($M=13.06$ s, $SD=2.48$, $p=.04$) and the person ($M=10.45$ s, $SD=1.48$, $p=.07$) than at the background ($M=5.22$ s, $SD=1.61$). The amount of time spent looking at the puppet and the person did not differ significantly. Overall, as shown in Figure 3, infants spent around 30% of their time attending to the puppet and to the person and around 12% of the time attending to the background.

No analyses were conducted on the viewing patterns of infants who watched the control video, because this video was only included to provide a similar experience for infants in the control condition prior to the VPC task.

Visual recognition memory

We then examined whether infants evidenced recognition memory for the individual components shown on the demonstration video. Visual recognition memory was determined by comparing the proportion of looking to the “novel” test image (puppet, person, background) to chance level of looking (0.5) using one sample t -tests. Table 1 shows the amount of time infants spent fixating on the novel images as a percentage of the total looking time during the test session. Given that interpretations of the direction of preferences (novelty or familiarity) remain controversial (for review see Houston-Price & Nakai, 2004; Pascalis & de Haan, 2001), looking significantly longer at either the “novel” or the “familiar” image in the image pairs can be taken to indicate recognition memory. Note that although each infant

was presented with all three recognition tests, not all infants contributed usable data for each recognition test. Therefore the number of participants varies across each test, as shown in Table 1.

To determine whether the test images were broadly equivalent in attractiveness, one sample *t*-tests were run on the control group VPC data. Overall, infants in the control group did not show a visual preference for any of the “novel” or “familiar” stimuli (see Table 1). This confirms that children who have not previously seen the target items (person, puppet, background) do not show a spontaneous visual preference for one item within a pair. Thus, a preference for any of the stimuli by infants in the experimental group indicates evidence of recognition memory.

For infants in the experimental group, there was no significant main effect of age, $F(1,22) = .022, p=.883$, VPC test image, $F(2,44) = 2.281, p=.114$ or an interaction effect between age and VPC test image, $F(2,44) = .212, p=.810$. However, one sample *t*-tests revealed that 9-month old infants showed a significant preference for the familiar person, $t(14) = -2.527, p=.024$, and 6-month old infants showed a marginally significant preference for the familiar person, $t(13) = -2.081, p=.058$. There was no evidence of preferential looking at the puppet (6-months: $t(14) = .296, p=.772$; 9-months: $t(15) = .344, p=.735$) or background (6-months: $t(14) = -1.544, p=.145$; 9-months: $t(12) = -.903, p=.384$). Thus, irrespective of age, infants displayed some evidence of recognition memory for the person, but not for the puppet or the background.

Discussion

Previous studies have shown that infants as young as 6-months of age can learn actions demonstrated on a video (e.g., Barr et al., 2007), but that there are dramatic age-

related changes in the duration and flexibility of learning from live and video demonstrations over the first years of life (for review, see Barr 2010; Hayne, 2004). This exploratory study revealed no differences in the gaze patterns of 6- and 9-month olds as they watched the video of a person demonstrating actions with a puppet. At both ages, infants attended to the video for the same duration and focused their gaze primarily on the person and the puppet, whilst allocating approximately 12% of their visual attention to scanning the background. Thus, there is no evidence to suggest that changes in the focus of attention during encoding might be responsible for age-related changes in the flexibility of infant memory observed between 6- and 9-months of age (e.g., Herbert, Gross, & Hayne, 2006; Learmonth et al., 2004).

To date, assumptions about what infants attend to and encode into memory have come largely from studies in which there are changes in elements of the target event between encoding and retrieval. For example, the failure of young infants to retrieve a memory in the presence of a new person, or in a new context, implies that these aspects of the original event had been attended to and encoded into the memory representation (e.g., Hayne, Rovee-Collier, & Borza, 1991; Hayne et al., 1997, 2000; Hartshorn et al., 1998; Jones & Herbert, 2008; Robinson & Pascalis, 2004). In contrast, eye tracker methodology provides infancy researchers with the opportunity to establish which aspects of an event are the focus of infant visual attention at encoding. In the present study, infants primarily attended to the puppet and the person, rather than scanning the scene more broadly. There are a number of possible reasons why infants showed these looking patterns. The least theoretically interesting possibility is that infants are simply attracted to the movement of these stimuli on the screen. However, if attention is purely driven by stimulus movement, then it is surprising that our infants allocated 12% of their viewing time to the background, which does not move. We believe that a more compelling account for why the puppet and the person received more viewing time than the background is that by 6-months of age, infants are already able to place cues in order of importance – the background is simply a less important part of the viewing

event, and thus warrants less visual attention. This account would be consistent with the theoretical view that differences occurring during memory acquisition, such as the importance placed on each cue, might be responsible for age-related changes in the flexibility of memory performance across a change in contextual and social details (see Jones & Herbert, 2006).

The similarity between the scanning patterns of the 6- and 9-month old infants in the present study contrasts with the developmental changes in the focus of visual attention observed by Frank et al. (2009) between 3- and 9-months of age. However, our study used a silent video, while the stimuli in that study were 24 10s segments from a Charlie Brown cartoon, which had been designed to provide infants with rich visual and linguistic input. As Frank et al. (2009) themselves note, infants' developing abilities to match faces with voices may have contributed to the developmental differences that were observed in the infants' scanning patterns. Certainly within the imitation literature, the addition of language cues at encoding and retrieval has been shown to increase the duration of retention and the flexibility of early memories, at least from 12-months of age (e.g., Bauer, Hertsgaard, & Wewerka, 1995; Bauer et al., 2000; Hayne & Herbert, 2004; Herbert, 2011). Further research is needed to determine the extent to which language cues change or direct attention during encoding.

In addition to considering the learning process, eye tracker methodology is particularly well-suited to assessing visual recognition memory, at least in part because it provides an automatic record of looking time, without the need for frame-by-frame analysis of looking time from videos. However, it is important to question why there was only limited evidence of recognition memory in the present study. In a typical VPC procedure, the infant is presented with a static image for a set period until habituation occurs. Following a delay, the same image is presented simultaneously with a new static image. In contrast to this standard procedure, we presented infants with a complex video at encoding, and then used photographs of each individual component as the test stimuli. Infants under 9 months of age can transfer knowledge across visual presentations, including 2D to 3D transfers (for review see Barr,

2010), although less is known about the transfer of learning from a moving 2D presentation to a static 2D representation at this age. It is possible that younger infants might need additional encoding time when required to make a transfer of knowledge from moving images at encoding to static images at test. Previous VPC studies have shown that short encoding times (Slater, 1995), complex moving stimuli (Sophian, 1980; Brown, Robinson, Herbert, & Pascalis, 2006) and changes to the background between encoding and retrieval (Jones, Pascalis, Eacott, & Herbert, 2011; Robinson & Pascalis, 2004) can disrupt recognition memory performance, resulting in familiarity or null preferences. It remains to be determined whether the familiarity preferences for the person, observed in this study with 9 month olds, and to some extent with 6 month olds, relates to previous imitation research showing that these age groups fail to retrieve their memories with people who were not present at encoding (e.g., Learmonth et al., 2005).

The next step in our research programme is to determine whether individual infant's viewing patterns during learning are correlated with their recognition and recall for the event. A larger sample of typically developing infants is currently being studied with the aim of identifying infants with particular scanning patterns during learning, such as higher levels of attention to the person, so that we can directly examine whether their memory performance is more or less sensitive to the identity of the person present, and how this might change as a function of age. Comparisons across different memory outcomes will be especially informative given the finding that infants may fail to show recognition memory for the puppet following a live demonstration but still successfully exhibit behavioural recall for the target actions (Gross, Hayne, Herbert, & Sowerby, 2002).

In summary, this present findings represent an important first step in combining together new technology, which can provide insight into what infants are actually observing during encoding, with well-established memory procedures, which show how infants use this knowledge at a later date. If, as William James (1890) proposes, "Only those items which I

notice shape my mind” (p.402) then, by attending to the same components during learning, 6- and 9-month old infants appear to have similar opportunities to be shaped.

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Table 1.

Proportion of looking to the novel stimulus by 6- and 9-month old infants in the recognition test as a function of condition.

Age	Experimental						Control					
	<i>Proportion of looking to the novel stimulus (SD)</i>						<i>Proportion of looking to the novel stimulus (SD)</i>					
	<i>N</i>	Puppet	<i>N</i>	Person	<i>N</i>	Background	<i>N</i>	Puppet	<i>N</i>	Person	<i>N</i>	Background
6-months	15	.52 (.22)	14	.40 ^A (.19)	15	.43 (.18)	10	.52 (.24)	9	.41 (.19)	8	.50 (.20)
9-months	16	.52 (.22)	15	.39* (.16)	13	.45 (.21)	9	.49 (.19)	10	.41 (.20)	7	.43 (.25)

* p<.05

^A p<.06

Figure captions

Figure 1. Screenshot of the experimental video, and b) recognition tests for the person, puppet, and background.

Figure 2. Screenshot of the experimental video identifying the 3AOIs: background, puppet, person

Figure 3. Six and 9-month old infants' mean percentage looking time ($\pm 1 S.E.$) to the experimental video as a proportion of the time spent looking at each AOI.

Figure 1.

a



b



Figure 2.

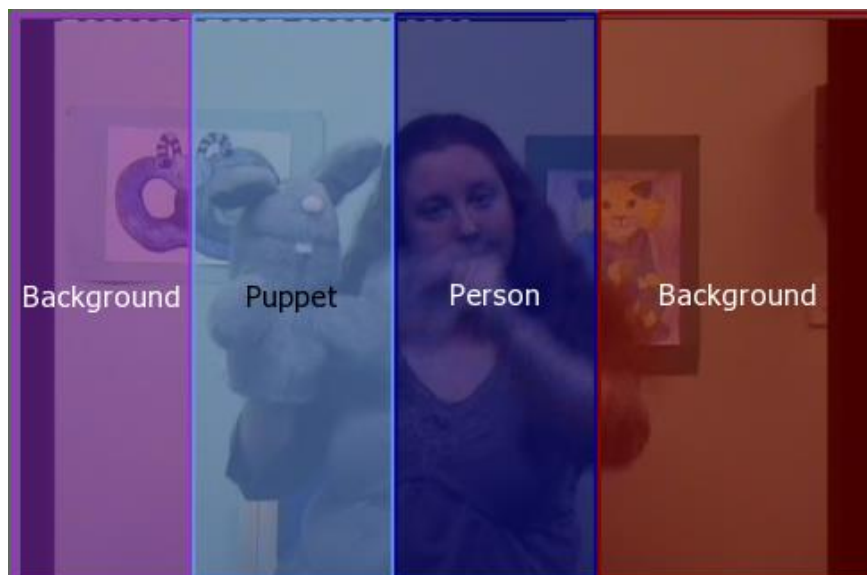


Figure 3:

