Vision Research 210 (2023) 108265

Contents lists available at ScienceDirect

Vision Research

journal homepage: www.elsevier.com/locate/visres

Frequency of adapting events affects face aftereffects but not blur aftereffects

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ARTICLE INFO

Keywords:
Visual adaptation
Blur aftereffects
Face aftereffects
Adapting events

ABSTRACT

The dynamics of visual adaptation remain poorly understood. Recent studies have found that the strength of adaptation aftereffects in the perception of numerosity depends more strongly on the number of adaptation events than on the duration of the adaptation. We investigated whether such effects can be observed for other visual attributes. We measured blur (perceived focus-sharp vs blurred adapt) and face (perceived race- Asian vs. White adapt) aftereffects by varying the number of adaptation events (4 or 16) and the duration of each adaptation event (0.25 s or 1 s). We found evidence for an effect of event number on face but not on blur adaptation, though the effect for faces was significant for only one of the two face adapt conditions (Asian). Our results suggest that different perceptual dimensions may vary in how adaptation effects accrue, potentially because of differences in factors such as the sites (early or late) of the sensitivity changes or nature of the stimulus. These differences may impact how and how rapidly the visual system can adjust to different visual properties.

1. Introduction

Visual adaptation refers to the ability of the visual system to continuously adjust to the varying viewing contexts by changing its operating properties, a process that facilitates efficient visual coding and contributes towards perceptual constancy (Webster 2015). Visual adaptation results in diminished sensitivity to the adapting stimulus, biasing the perception of subsequently presented stimuli relative to the adapting stimulus. For example, after adaptation to an oriented grating, a subsequently shown grating appears to be rotated away from the adapting orientation, a phenomenon known as the tilt aftereffect (Campbell & Maffei 1971; Gibson & Radner 1937; Jin et al. 2005). Such aftereffects have been found for a wide range of stimulus features ranging from simple, low-level stimulus properties such as mean light level (Dowling 1967) and contrast (Greenlee & Heitger 1988) to complex, high-level properties such as face identity, ethnicity, and gender (Leopold et al. 2001; Webster et al. 2004).

Visual adaptation can occur over multiple timescales (Solomon & Kohn 2014; Webster 2015). Studies focusing on adaptation ranging from seconds to minutes have reported that the magnitude and duration of aftereffects are directly proportional to the duration of adaptation (Bao & Engel 2012). For example, brief adaptation to a stimulus property such as contrast revealed that with an increase in adaptation time, the magnitude and duration of aftereffects is well described by a power law of time (Greenlee et al. 1991). Similar patterns of dynamics of build-up and decay of aftereffects are observed for higher level more abstract stimulus properties such as faces (Leopold et al. 2005). These results suggest the potential existence of common mechanisms underlying brief adaptation to different stimulus categories that are processed at various stages of the visual stream.

Although the pattern of build-up and decay is similar for aftereffects resulting from adaptation to low-level and high-level stimulus properties, the rate of adaptation build-up and decay may vary along the stage of processing in the visual hierarchy at which the adaptation occurs. A recent psychophysical study has shown that the magnitude and timescales of adaptation effects are different for stimuli processed at early stages and mid-stages of visual processing (Mei et al. 2017). Specifically, adaptation effects at mid-level stages had a greater magnitude and slower decay compared with effects at early-level stages. Further, Suzuki & Cavanagh (1998) using a shape distortion effect showed that adaptation to high-level configural shapes is more rapid. Thus, the temporal characteristics such as the build-up and decay rate of adaptation

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https://doi.org/10.1016/j.visres.2023.108265
Received 3 April 2023; Received in revised form 17 May 2023; Accepted 17 May 2023

aftereffects might be stimulus and processing-level dependent.

Recent findings have challenged the conventional understanding of adaptation duration as directly proportional to the magnitude and duration of aftereffects. After adapting to patches with a high or low number of dots, Aagten-Murphy & Burr (2016) reported that a standard test array was perceived as less or more numerous, respectively. Interestingly, they found that such numerosity adaptation can be induced by brief exposures, and that the magnitude of aftereffects was primarily determined by the number of adapting events. Specifically, when the total adaptation duration was kept equal, the condition with more events induced higher adaptation effects than the condition with fewer events. When the number of adaptation events was kept identical, shorter events were equally effective as longer events. These results provide evidence that neither the duration of each adapting event nor the total duration of exposure to the adapting stimuli had significant influence on numerosity adaptation.

To our knowledge, the study by Aagten-Murphy & Burr (2016) is the only study that showed greater adaptation effects with increased frequency of adaptation events regardless of exposure duration. Neural imaging studies have indicated that parietal cortex - especially the intraparietal sulcus responds to the manipulation of numerosity, providing evidence that numerosity is likely processed at later stages of the visual stream (Eger et al. 2009; Piazza et al. 2007). It is not clear whether the effects of event number reported for numerosity reflect mechanisms that are unique to high-level visual adaptation. Using an experimental design motived by Aagten-Murphy & Burr (2016), we tested whether similar effects of event number can be found for blur and face aftereffects. Specifically, we varied the number of adaptation events (4 or 16) and the duration of each adaptation event (0.25 s or 1 s) and measured blur adaptation and face ethnicity adaptation aftereffects. We chose blur and face aftereffects because both reflect natural and salient visual attributes that lead to robust adaptation effects (Webster et al. 2002; 2004). Additionally, blur adaptation probably adjusts for the natural aberrations caused by observer's optics since the environment is mostly focused (Sawides et al. 2011). Conversely, because of the natural variability of faces adaptation to faces may be driven more by variability in the environment than the observer (Burton 2013; Webster & MacLeod 2011).

2. General methods

2.1. Participants

A total of 30 participants were recruited from the University of Nevada, Reno (UNR) and surrounding areas. Fifteen participants (Mean age: 24.7 years, range: 18 – 34 years, 7 females) participated in the blur adaptation experiment, and 15 participants (Mean age: 22.25 years, range: 18–31.4 years, all female) participated in the face adaptation experiment. Since we used White and Asian female faces in the face adaptation experiment, we only included White females' participants to minimize the bias of participants' own ethnicity and gender on face categorization (Webster et al. 2004). All participants reported normal or corrected-to-normal vision. The study protocols were reviewed and approved by the Institutional Review Board at the University of Nevada, Reno in accordance with the Declaration of Helsinki. Participation was with informed consent and participants were compensated for their time.

2.2. Apparatus

Stimuli were presented on Display++ LCD monitor (Cambridge Research Systems, Rochester, UK) with 1920 X 1080 resolution, a refresh rate of 120 Hz, and a mean luminance of 120 cd/m^2, and a CIE 1931 chromaticity of × = 0.30, y = 0.31 (measured with PR-655 spectrophotometer, SpectraScan, Syracuse, NY). Participants observed the screen binocularly from a 75 cm distance in all three experiments. Stimuli were generated and presented using MATLAB 2021a using PsychToolbox routines (Brainard 1997; Pelli 1997). All experiments were carried out in a dark room.

3. Stimuli

3.1. Blur adaptation

To test the adaptation aftereffects to image blur, we used a natural color image from an open-source website (https://www.unsplash.com). We varied the slope of the amplitude spectrum from −1 to + 1 in 0.02 steps relative to its original slope of −1.1 to generate a continuous series of 101 images which ranged from strongly blurred to strongly sharpened respectively. All the resultant images were scaled so that they had the same rms contrast and mean luminance (~113 cd/m^2) as the original image. At testing distance of 75 cm the images spanned a visual angle of 5 deg. We used the blur and sharp image with slope changes of −1 and + 1 shift as adaptors (see Fig. 1A).

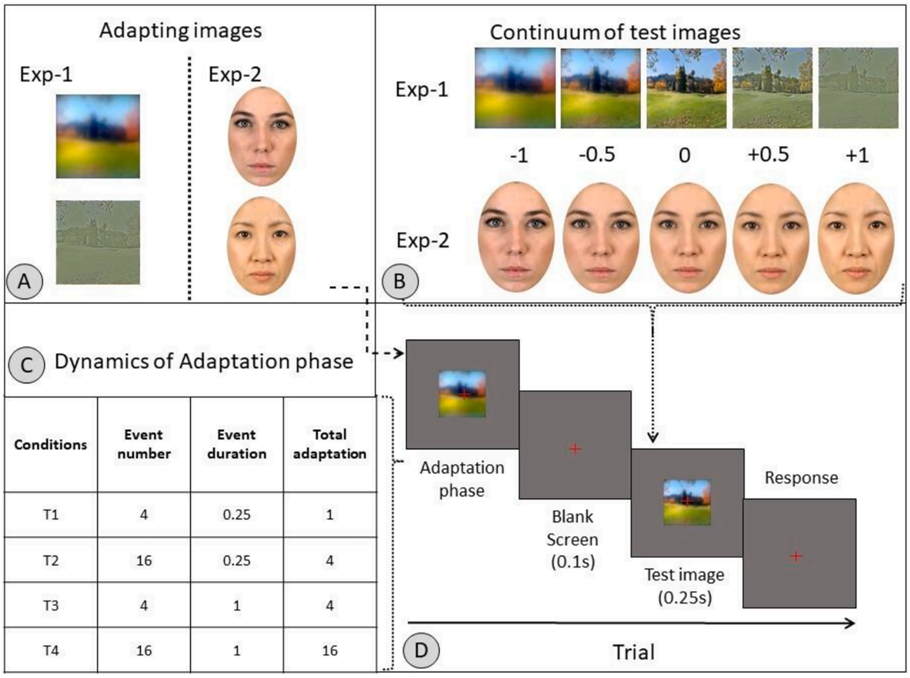
3.2. Face adaptation

To test the adaptation aftereffects of face ethnicity, we used a single Asian and White female face from the Chicago Face Database (Singh et al. 2022). We cropped the images to remove the external features. Using FantaMorph software (https://www.fantamorph.com), we morphed these face images to generate a finely graded series of face images ranging between the two original face images. To have a comparable scale of measure between blur adaptation and face adaptation experiment, we assigned ethnicity values from −1 for original White female face to + 1 for original Asian female face in steps of 0.02, with the ethnicity value of the nominally neutral face (50% Asian and 50% White) being zero. At the testing distance of 75 cm, the presented face images spanned a horizontal visual angle of 5 deg and vertical visual angle of 7.5 deg. We used the original Asian face image and White face image as adaptors (see Fig. 1A).

3.3. Procedure

In both blur and face experiment, we measured the point of subjective equality in a baseline condition (pre-adapt) using a one-down one-up staircase with a two-alternate forced choice task (2-AFC). Each trial started with a display of the test image for 0.25 s followed by a blank screen. The next trial started after the participant's response was recorded. The staircase varied the slope of the image amplitude spectrum and continued for 40 trials.

In the adaptation conditions, each trial started with an adaptation phase by displaying the adaptors (blur/sharp image, Asian/White face image) for two duration levels (0.25 s and 1 s) and two levels of event number (4 and 16 times) resulting in a total of 4 unique adapting conditions (see Fig. 1C). Between the two events there was a blank screen for 0.1 s. After the adaptation phase we displayed a blank screen for 0.1 s followed by the test image for 0.25 s. For both experiments, the adaptors were presented at the center of the screen and test stimuli was presented 0.4 or 0.8 deg off-center either up, down, left, or right to eliminate the effects of adaptation to spatial information. In each trial, participants were shown the adaptor (specifications based on condition tested, see Fig. 1C) followed by a blank screen for 0.1 s. The blank screen was followed by a test stimulus which was displayed for 0.25 s after which the screen was again blank, see Fig. 1D. Participants were asked to perform a two-alternative forced choice task, in which they were asked to judge whether the test stimuli appeared Blurred/Sharp or Asian/White. The stimulus level was varied in a one-up one-down staircase, which ended when participants completed a total of 40 trials. In contrast to conventional staircase procedures, we did not define the end of the staircase by the number of reversals as it may have resulted in differences in the number of total trials tested. Participants took an 8–10 min



Conditions	Event number	Event duration	Total adaptation
T1	4	0.25	1
T2	16	0.25	4
T3	4	1	4
T4	16	1	16

Fig. 1. (A) Illustrates the pair of adaptors used in blur and face adaptation experiment. (B) Shows the subset of continuum of images used as test images during staircase in blur and face experiment. (C) Represents the number of events and event duration in each condition for all experiments. (D) Illustrates an example trial in blur adaptation experiment.

break after completing each condition. The order of adaptors within each experiment was counterbalanced across participants and the order of the 4 conditions for each adaptor was randomized.

Note that we used a different adaptation paradigm than Aagten-Murphy & Burr (2016). After the adaptation period, they examined the influence of event number and event durations on the strength of adaptation effect and tracked the rate of decay of adaptation effects. In the present study, we focused on the overall magnitude of the adaptation effect rather than its build-up and decay. Thus, we used conventional one-down and one-up staircase method and examined the effects of event number and event duration on the overall magnitude of adaptation aftereffects.

4. Analysis

The point of subjective equality (PSE) after adaptation was calculated by taking the average of slope or ethnicity values from the last six reversals of the staircase. PSE was measured once before (e.g.: $\text{PSE}_{\text{baseline}}$) and then after adaptation in all four adapting conditions for each adaptor in both blur and face experiment. The magnitude of adaptation

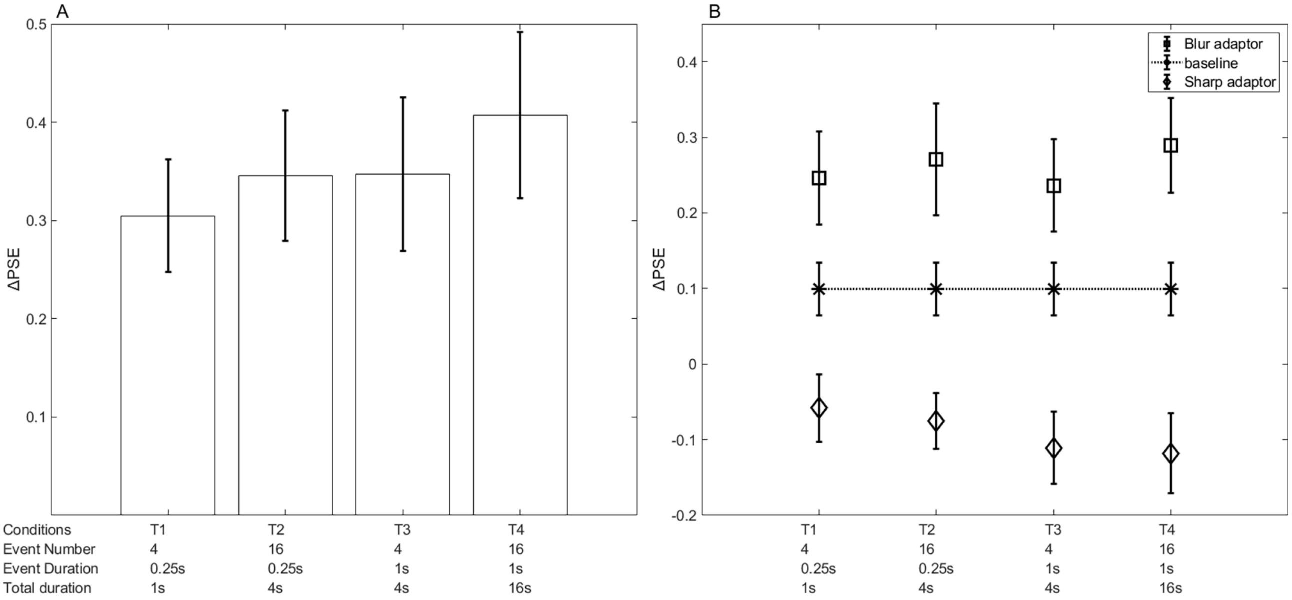


Fig. 2. (A) Blur adaptation experiment results. The magnitude of adaptation effect (ΔPSE) was plotted for each condition. Error bars represent standard error. X-axis labels show the event number and event duration in each condition and total adaptation time in each condition. (Also see Figure-1C). (B) Mean and standard error of ΔPSE obtained in the blur experiments, with ΔPSEs for blur adaptor shown in square markers, ΔPSEs for sharp adaptors shown in diamond markers, and baseline PSE shown in asterisk marker. Note that baseline PSE was measured once before adaptation and was used to obtain ΔPSE in all conditions for both adaptors.

effects (ΔPSE) for each condition was calculated as the difference between the PSE obtained from two opposing adaptors (e.g.: $\Delta PSE_{T1} = PSE_{T1(blur)}$- $PSE_{T1(sharp)}$) (Habtegiorgis et al. 2017). Adaptation effects were then evaluated with a two-way ANOVA with two levels corresponding to event duration (0.25 s and 1 s) and number of events (4,16). All statistical analyses were performed in JASP statistical software (JASP Team, 2023).

We also quantified the magnitude of adaptation effects separately for each of the two opposing adaptors as the difference between the PSE obtained after adaptation in each condition and baseline PSE (e.g.: ΔPSET1(blur) = PSET1(blur adaptor)- PSE baseline). We submitted the ΔPSE obtained for each adaptor and ran separate two-way ANOVAs to examine the magnitude of adaptation effects with two levels corresponding to event duration (0.25 s, 1 s) and event number (4, 16) (see Fig. 2B and Fig. 3B).

Further, we performed a 3-way ANOVA on the ΔPSE values obtained from the two opposing adaptors in the blur and face conditions to examine the main effects of 1) stimulus property (blur, face); 2) event duration (0.25 s, 1 s); and 3) number of events (4, 16), along with their interactions. To understand and interpret any non-statistically significant results, we calculated Bayes factors (BF_{10}) in JASP statistical software (JASP Team, 2023) with default priors (Rouder et al. 2012).

5. Results

In the blur adaptation experiment, adaptation effects were similar across conditions (Fig. 2). There was no significant main effect of event duration (F (1,14) = 0.973, MSE = 0.04, p = 0.341), no significant main effect of event number (F (1,14) = 2.291, MSE = 0.38, p = 0.152), and no significant interaction between event number and event duration (F (1,14) = 0.112, MSE = 0.001, p = 0.743). Although the adaptation magnitude increased from T1 (M1 = 0.306, SD = 0.22) to T4 (M = 0.407, SD = 0.38) as the total adaptation increased from 1 s to 16 s, they were not significantly different (t (14) = -1.47, p = 0.16). To determine the likelihood of null hypothesis compared to other models we examined the data using Bayes Factors. All models were compared to the null model. Event duration (BF_{10} = 0.44) and event number alone (BF_{10} = 0.51) had anecdotal evidence to support the null hypothesis. The model containing both main effects and their interaction provided moderate evidence for the null hypothesis (BF_{10} = 0.13) (see Fig. 2A).

Similarly, null results were obtained when the adaptation effects were assessed separately for the blur and sharp adaptor against the baseline PSE (see Fig. 2B). We found that with the blur adaptor, there was no significant main effect of event duration (F(1,14) = 0.01, MSE = 0.0002,p = 0.92, BF10 = 0.46), no significant main effect of event number (F(1,14) = 3.68, MSE = 0.02, p = 0.08, BF10 = 0.72), and no significant interaction between event number and event duration (F (1,14) = 0.43, MSE = 0.003, p = 0.53, BF10 = 0.25). The model containing the main effects of event number, event duration, and their interactions provided moderate evidence for the null hypothesis (BF10 = 0.18). Similarly, for the sharp adaptor, there was no significant main effect of event duration (F(1,14) = 2.49, MSE = 0.03, p = 0.14, BF10 = 0.64), no significant main effect of event number F(1,14) = 0.37,MSE = 0.002, p = 0.554, BF10 = 0.28), and no significant interaction between event number and event duration (F(1,14) = 0.044, MSE = 0.0003, p = 0.836, BF10 = 0.19). The model containing event number, event duration, and their interaction provided moderate evidence for the null hypothesis (BF10 = 0.12).

In the face adaptation experiment, the main effect of event number on face aftereffects was significant (F (1,14) = 13.98, MSE = 0.660, p = 0.002). As seen in Fig. 3, ΔPSE in conditions with 4 events (T1 and T3) were lower than the conditions with 16 events (T2 and T4). However, the main effect of event duration on face adaptation (F (1,14) = 0.00, MSE = 0.0001, p = 0.984) and the interaction between event number and event duration (F (1,14) = 1.162, MSE = 0.021, p = 0.299) did not reach significance. To examine the effect of total adaptation duration on ΔPSE we further compared conditions T1 and T4 with a paired *t*-test. We found a significantly lower ΔPSE in T1 (M = 0.79, SD = 0.35) compared to T4 (M = 1, SD = 0.23), t(14) = -3.09, p = 0.004. To examine the effect of increased number of events while keeping the total adaptation time constant, we compared T2 and T3 conditions. ΔPSE was significantly higher in T2 (M = 0.96, SD = 0.31) than in T3 (M = 0.75, SD = 0.35), t (14) = 3.315, p = 0.003. To determine the likelihood of rejecting the null hypothesis we examined the Bayes Factors. All models were compared to the null model. As expected from the ANOVA results, there is strong evidence in favor of a presence of effects of event number (BF10 = 12.28) on adaptation effects. There was anecdotal evidence in favor of absence of effects of event duration (BF10 = 0.5) and their

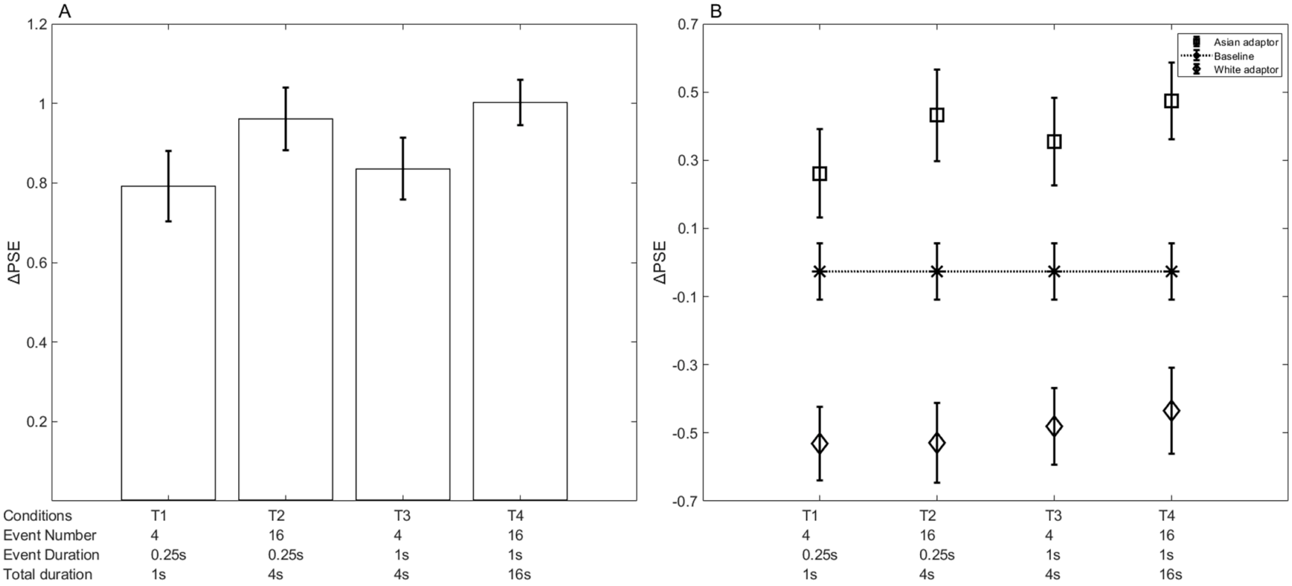


Fig. 3. (A) Face adaptation results. The magnitude of adaptation effect (ΔPSE) was plotted for each condition. Error bars represent standard error. (B) Mean and standard error of ΔPSE obtained in the face experiment, with ΔPSEs for Asian face adaptor shown with square markers, ΔPSEs for White face adaptors shown in diamond markers, and baseline PSE shown in asterisk marker. Note that baseline PSE was measured once before adaptation and was used to obtain ΔPSE in all conditions for both adaptors.

interaction (BF10 = 0.36) (see Fig. 3A).

Assessments of the adaptation effects quantified separately for Asian and White face adaptors (relative to the baseline PSE), showed that the significant effect of event number was driven by the Asian face adapt conditions (see Fig. 3B). For Asian face adaptor, we found that there was a significant main effect of event number (F(1,14) = 9.02, MSE = 0.31,p = 0.009, BF10 = 4.66), with adaptation effects in conditions with 16 events (M = 0.453, SD = 0.5) significant higher than conditions with 4 events (M = 0.31, SD = 0.5). We also found a significant main effect of event duration (F(1,14) = 5.186, MSE = 0.07, p = 0.04, BF10 = 0.81 (anecdotal evidence for the null hypothesis)), with adaptation effects in conditions with 1 s (M = 0.41, SD = 0.46) higher than in conditions with 0.25 s (M = 0.347, SD = 0.51) (see Fig. 3B). We found no significant interaction between event number and event duration (F(1,14) = 0.46, MSE = 0.01, p = 0.51, BF10 = 0.72). The model containing the main effects of event number provided moderate evidence for accepting the alternate hypothesis. For White face adaptor, we found no significant main effects of event number (F(1,14) = 0.246, MSE = 0.008, p = 0.63, BF10 = 0.27) and event duration (F(1,14) = 1.63, MSE = 0.08,p = 0.22, BF10 = 0.45), and no significant interaction between event number and event duration (F(1,14) = 0.22, MSE = 0.01, p = 0.65, BF10 = 0.15). With relatively higher magnitude of adaptation effects across 4 adapting conditions, it is possible that adaptation induced by White face adaptation has reached saturation for White female participants we tested.

A 3-way ANOVA analysis was carried out to examine the main effects and interactions of stimulus property (blur, face), event duration (0.25 s, 1 s) and event number (4, 16). We found significant main effects of event number (F(1,14) = 13.11, MSE = 0.36,p = 0.003, BF10 = 14.56) and stimulus property (F(1,14) = 44.81, MSE = 8.96, p < 0.001, BF10 > 1000) on the magnitude of adaptation. Overall, a higher magnitude of adaptation was observed in conditions with 16 events (see Fig. 4). The effect of stimulus property is again because the scales for faces and blur were not comparable. We found no significant main effect of event duration (F(1,14) = 2.58, MSE = 0.07, p = 0.13, BF10 = 0.51, anecdotal evidence for null hypothesis). The model containing event number and stimulus property provided extreme evidence in favor of alternate hypothesis (BF10 > 1000).

The two-way interaction between event number and stimulus property approached but did not reach significance (F(1,14) = 3.98, p = 0.066, BF10 = 3.15, moderate evidence in favor of interaction). Post-hoc comparisons revealed that in the blur experiment there was no significant difference in the magnitude of adaptation between conditions with 4 events (M = 0.33, SE = 0.06) and conditions with 16 events (M = 0.38, SE = 0.071) (t(14) = -1.514, p = 0.152). On the other hand, in the face experiment the magnitude of adaptation increased as event number increased from 4 (M = 0.81, SE = 0.07) to 16 (M = 0.98, SE = 0.072) (t (14) = -3.403, p = 0.004) (see Fig. 4). The two-way interactions between stimulus type and duration or between duration and event number were not significant (p's > 0.8, BF10 = 0.5 and 0.42 respectively). Finally, There was not a significant 3-way interaction, (F(1,14) = 0.082, p = 0.78, MSE = 0.001, BF10 = 0.17). The model containing event number and stimulus property provided extreme evidence in favor of alternate hypothesis (BF10 > 1000).

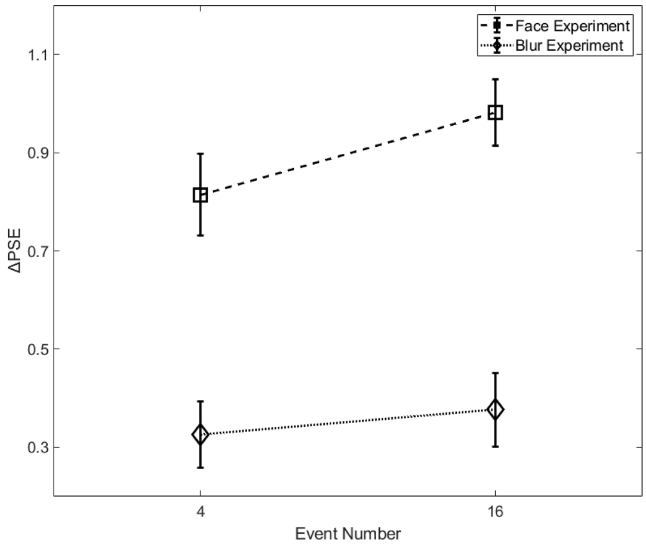


Fig. 4. Plot showing interaction between number of events and stimulus property (significant two-way interaction) revealed by 3-way ANOVA on ΔPSE obtained from two opposing adaptors in blur and face experiments examining the main effects of stimulus property (blur, face), event duration (0.25 s, 1 s) and their interaction, averaged across event durations. Means and standard errors of ΔPSE are shown in square markers for face and in diamond markers for blur.

6. Discussion

The purpose of this study was to examine whether the effects of event number previously reported for numerosity adaptation (Aagten-Murphy & Burr 2016) can be found for other visual stimuli. We included adaptors to examine blur and face aftereffects in conditions with varied number of events and duration of each event. For blur adaptation, we did not find a significant effect of event number, indicating the finding of Aagten-Murphy & Burr (2016) may be specific for certain stimuli rather than a general feature of adaptation. Interestingly, for our conditions we also did not find a significant effect of adaptation duration. Only brief periods of exposures were sufficient to induce an adaptation effect achieved by longer adaptation. Although we observed a trend of increase in magnitude of adaptation with increase in total adaptation duration, this was not statistically significant. Our data thus did not reveal the relation between blur adaptation duration and magnitude of adaptation effects with limited adaptation durations we used (1 s – 16 s). The effects of duration on blur adaptation have typically been explored at longer durations spanning minutes to hours and using a variety of dependent measures (George & Rosenfield 2004; Cufflin & Mallen 2020). On the other hand, the perceptual changes in blur of the kind we measured typically occur rapidly with adaptation (e.g. Webster et al., 2002), and are also characteristic of other contrast adaptation effects in vision (Greenlee et al. 1991). Studies with a broader range of event durations and event numbers as well as a broader range of tasks (e.g. contrast sensitivity or acuity) will be important for a fuller understanding of the dynamics of blur adaptation.

On the other hand, over this same duration in the face adaptation experiment, we found that face adaptation was influenced by the number of adaptation events. Specifically, we observed similar adaptation effects between conditions with the same number of events but different event duration (i.e., T1 and T3; T2 and T4). These results are consistent with the findings of Aagten-Murphy & Burr (2016). Furthermore, when the total adaptation duration was kept constant, higher adaptation effects were induced in the condition with the higher number of events. Combined, our results from two experiments suggest that increasing adaptation frequency significantly impacted the magnitude of face but not blur adaptation effects. However, these differences were asymmetric for the face adaptation again such that the effects of event number reached significance for only one of the two opposing face adaptors. Moreover, as noted previously, robust effects of exposure duration have been found previously for face adaptation, with a time-course that parallels adaptation to other visual attributes such as pattern contrast (Leopold et al. 2005; Rhodes et al. 2007). Thus, while effects of event number on faces were significant, they appear to be less strong than those previously reported for numerosity (Aagten-Murphy & Burr 2016), suggesting that the dynamics of numerosity adaptation may still be very different from face (or blur) adaptation.

Studies have shown that aftereffects increase with an increasing duration of the adapting stimulus and decay over time with a power law behavior (Bao & Engel 2012). This relationship has been well established for simple aftereffects such as tilt (Harris and Calvert 1989; Magnussen and Johnsen 1986), motion (Hershenson 1989) and contrast (Greenlee et al. 1991). Leopold et al. (2005) conducted a study on the effects of adaptation duration on face aftereffects. In their study, the adaptation duration varied from 1 s to 16 s. The results provide evidence that face aftereffects increase with adaptation duration. Consistent results were obtained for face identity aftereffects even when the contribution of low-level adaptation was reduced by size changes between the adaptor and test stimuli (Rhodes et al. 2007). These findings point towards the similar temporal dynamics of adaptation across stimulus features. However, our findings that adaptation effects increased with the number of adapting events for face but not for blur suggest that some dynamics of adaptation might differ across stimulus features.

While the neural representations of facial identity and image blur differ in many ways, one notable difference may be in the level of processing along the visual hierarchy. Although there is no conclusive evidence, some evidence suggests that image blur is decoded in earlier visual areas, while faces are processed in higher visual areas. Blur adaptation might partly depend on processes related to spatial frequency adaptation, which is also thought to originate at early cortical levels (Mon-Williams et al. 1998). In addition, tuning to natural 1/f amplitude spectrum slopes has been found in early visual areas (Field 1987; Isherwood et al. 2017). On the other hand, faces are considering a prototype of high-level visual processing involving specialized cortical networks such as the fusiform face area, lateral fusiform area, superior temporal sulcus (Duchaine & Yovel 2015; Hoffman & Haxby 2000; Kanwisher et al. 1997; Kanwisher & Yovel 2006). Additionally, studies have also shown that the temporal characteristics of processing differ with these stages of processing (Hasson et al. 2008; Himberger et al. 2018). These may in turn reflect the differences in the hierarchy of adaptation effects reported by Mei et al. (2017), where they found weak adaptation and rapid decay for stimuli processed at early-level stages of visual processing compared to those processed at mid-level stages of visual processing. An alternative possibility is that differences in how vision adjusts could reflect differences in the properties of the stimulus changes themselves. For example, the dynamics of motor adaptation depend on the rates of change in the body (Kording et al. 2007). In this regard, blur in the retinal image is more likely to arise from aberrations in the in the optics of eye (Sawides et al. 2011) rather than changes in the statistics of the environment, and therefore represents a case where the adaptation is “compensating” for often long-term properties of the observer. In contrast, face adaptation requires adapting to the variability in observer’s social environment (Burton 2013; Webster & MacLeod 2011). It will be interesting to explore whether such differences could also influence the effect of event number on the dynamics of adaptation.

As suggested by Aagten-Murphy & Burr (2016), what constitutes an event is a further important question. In the present study when we fixed the number of events, increasing the duration of each event from 0.25 s to 1 s did not have a significant effect on adaptation effect for faces, suggesting an event duration of 0.25 s is sufficient to be registered as one unique event. Our findings are consistent with electrophysiological results using a fast periodic visual stimulation adaptation paradigm (FPVS) (Retter et al. 2021). They reported that exposures to face stimuli for small durations of 170 ms is optimal for face individualization task. Similarly, our results also suggest that adaptation paradigm with repeated presentations of adaptor for small durations is well suited for high-level aftereffects like faces but not for blur aftereffects. Thus, duration of each exposure as well as stimulus features should therefore be considered when defining events.

In conclusion, we found that unlike blur adaptation, the magnitude of face adaptation may depend partly on the number of adapting events over the timescales we assessed. Our results extend the findings of Aagten-Murphy & Burr (2016) on numerosity adaptation. The present study represented the first attempt to assess the role of the number of events in adaptation to different stimulus features. Future studies examining the changes in build-up and decay of adaptation as a function of event number vs. event duration may shed additional light on mechanisms underlying adaptation to various stimulus features.

7. Commercial relationships

None.

CRediT authorship contribution statement

Idris Shareef: Conceptualization, Investigation, Methodology, Visualization, Formal analysis, Methodology, Writing – original draft, Writing – review & editing. **Michael Webster:** Supervision, Validation, Investigation, Writing – review & editing. **Alireza Tavakkoli:** Conceptualization, Supervision, Investigation, Funding acquisition, Validation, Writing – review & editing. **Fang Jiang:** Conceptualization, Investigation, Methodology, Supervision, Funding acquisition, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgement

This material is based upon work supported by the Office of the Under Secretary of Defense for Research and Engineering under award number FA9550-21-1-0207. Any opinions, findings and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the U.S. Department of Defense.

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