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FACIAL EXPRESSION IDENTIFICATION WITH INTRASACCADIC STIMULUS SUBSTITUTION

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Extreme temporal condition for visual identification task is held. A gaze-contingent eyetracking study was used to assess how presaccadic stimulus influences the one presented during a reactive saccade. A strong forward masking effect is found. Identification rate of second image is below chance, but still in accordance with previous studies, where no masking was present. Identification rate, erratic responses, statistical connection with alternative response (2AFC task), physical properties of saccades are similar to simple intrasaccadic identification task [3; 5]. Two aspects of transsaccadic visual perception were hypothesized, possessing common temporal structure: sensoric (geometric primitive detection) and gnostical (naturalistically valid object identification).

Keywords: facial expression identification, facial expressions, eye movements, saccadic suppression, direct visual masking, transsaccadic perception.

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ИДЕНТИФИКАЦИЯ ЛИЦЕВЫХ ЭКСПРЕССИЙ В УСЛОВИЯХ ИНТРАСАККАДИЧЕСКОЙ СМЕНЫ СТИМУЛА

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Проводится анализ возможности восприятия эмоциональных экспрессий лица в предельных режимах экспозиции. С помощью тахистоскопии и айтрекинга исследуется влияние предсаккадической информации (изображения лицевых экспрессий) на идентификацию похожих изображений лица во время саккад. При выполнении 10°-саккады продемонстрирован сильный эффект прямой зрительной маскировки. Хотя частота корректной идентификации тест-объектов находится на уровне ниже шанса, полученные оценки носят закономерный характер. В вырожденной форме воспроизводятся тенденции, обнаруженные ранее в условиях, когда реактивная саккада инициировалась изображением не лица, а миниатюрного креста, не вызывающего маскировки [3; 5]: рейтинги корректной идентификации эмоций, структура ошибок, зависимость частоты идентификации от альтернативного выбора ответа, показатели целенаправленных саккад (кроме латентного периода). Эффект саккадического подавления не обнаружен. Анализ полученных данных позволил выделить два уровня организации транссаккадического восприятия, объединенные общей темпоральной структурой: нижний (сенсорный) уровень, связанный с обнаружением элементарных оптических и геометрических стимулов, и верхний (гностический), обеспечивающий идентификацию комплексных экологически и социально валидных объектов.

Ключевые слова: идентификация выражений лица, лицевые экспрессии, движения глаз, саккадическое подавление, прямая зрительная маскировка, транссаккадическое восприятие.

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Introduction

Environmental objects possessing enough significance consume somewhat around 80—85% of gaze fixation timespan for search, detection and identification. Duration share of saccades (15—20% of total gaze time) is still unclear despite being comparable to environmental events duration. It is common to explain that in terms of *saccadic suppression*, and attribute that to visual information aggregation and processing discontinuity (theoretically), when fixations are attributed being an active phase.

There is plenty of experimental evidence that saccadic suppression does exist, but is not a biological invariant and still context-dependent. Visual sensitivity thresholds rise during saccades and directly depend on saccade amplitude, spatial frequency (clear, prominent contour information yields higher suppression), inverse-dependent on luminance (lower luminance yields less suppression) and spatial location due to anisotropic visual field (forthcoming object of interest tends to attract zone of maximum visual saliency). Although higher contrast and spatial frequency facilitate saccadic suppression, semantic data acquisition during saccades is still possible [6; 9; 10; 16; 25; 29; 30]. Larger stimulus angular size, and higher background-to-stimulus luminance ratio lead to increased suppression. Structured background or detailed texture raise sensitivity threshold during saccades as well [6]. Mitrani, Yakimoff, Mateeff (1973) report that suppression appears if structured background exists at saccade onset, while remaining indifferent during other stages. That is attributed to the fact that structured background is perceived as a contrast for the purely intrasaccadic test-object, and initiating forward masking effect. Notably, the effect is canceled if test-object intersects temporal boundaries of saccade. The more structured the object is, the less it can be masked by an unstructured one [14; 33]. Low spatial frequencies are suppressed the most [7]. It can be derived from partially conflicting inferences, made by different researchers at various periods, that it is not the spatial frequency of the object and background that matters, but its ratio. Moreover, evidence exists about luminance affecting saccadic suppression under a certain set of conditions, but clear contours (i.e. *structure*) under the other [25].

Lack of metacontrast if there exists a temporal gap of stimulus was discovered by Deubel, Schneider, Bridgeman (1996). This does not violate visual act's *irreversibility principle*, since it involves revealing an image perceived earlier through the mask object, not restoring it. Studies have shown that distractor objects at foveal proximity facilitate contrast perception, whilst peripheral ones inhibit it; whereas masking objects sharing bands of spatial frequency and line orientations same as stimulus make the strongest effect [28]. Most of these studies registered saccadic suppression effect between -80 and +50 ms from saccade onset.

Classic experimental studies of saccadic suppression conducted in 60s—70s of the past century were using primitive geometric objects [18; 20; 23; 26; 32]. Dots, flashes and spatial gratings were utilised. Although past two decades had several studies involving naturalistic stimulus [13], possessing validity, none of them had studied intrasaccadic suppression of facial expressions.

Our research of perisaccadic visual perception is aimed at using naturalistically valid stimulus or socially relevant events, the main object being facial expressions during interpersonal interaction. Besides psychophysics of visual perception, how the object of perception is subjectively valued is of paramount importance, too, including its value during socializing or cooperative action. A series of experiments were held previously, studying facial expression identification (2AFC task) during reactive saccades; an additional task of assessing perceived location of the face was present. Correct identification rate turned out to be above chance (61%), which was reported previously [2; 3; 5; 34]. Values so high are far superior than results reported for light flashes or geometric figures with similar conditions [20; 26; 31], but still 15—20% lower than identifying facial expressions during free look. Expressions of joy and fear are identified the best (0.81 and 0.71 respectively), while anger and sadness are at the base level (0.54 and 0.56); notably, neutral expression is identified at below chance level (0.43).

Both correct and alternative expression types are important during forced choice task, because the response is based on visual attractiveness. That said, those expressions which possess the highest attractiveness are identified correctly when presented, but hinder the choice if given as an alternative possible response. The higher the chance to correctly identify the given expression is, the more masking effect it causes.

Erratic stimulus locations are perceived during saccadic transitions [17; 24], with space compression towards saccade endpoint [8; 19]. Irregardless of true stimulus position on the way of saccade, subjects report it nearby saccade endpoints (±0.6 dva for right-sided, and ±1.8 dva for left-sided saccades; 'dva' stands for *degrees of visual angle*). During trials, there is no environmental constancy violation reported, i.e. no part of visual stimulus was seen moving when it is not.

We distinguish three sequential stages of visual perception during transitive saccadic process: 1) looking at fixation cross before starting a saccade (-80 — 0 ms), with accuracy rate equal to static peripheral vision at the same angular distance; 2) accuracy rate steadily grows during saccade (48 ms being median saccade duration); 3) accuracy rate is maximized during initial stage of the following fixation (+48 — +180 ms from saccade onset), then stabilizes. No gaps or steep decline of accuracy levels were found during perisaccadic temporal range. Some tendency of identification rate decline was registered at -30 to -15 ms time range, but there was insufficient statistical power to confirm that data.

Empirical data suggests eye movement's sequential structure (fixation-saccade-fixation) does not disturb spatio-temporal dynamics of visual function. Perception of facial expressions goes on even during peak velocities have already been reached, both with foveal and peripheral vision (at least 10 dva, *horizontally*). It does not seem like suppression is active while identifying naturalistically valid stimuli, rather a common impairment of visual pattern perception caused by angular distance to the object of interest.

The findings acquired provide evidence for the phenomena different from *saccadic suppression*. Although procedurally similar, as we were using tachistoscopy (with a CRT display), there were the following substantial modifications: 1) naturalistically valid images (possessing evolutionary value) were used instead of abstract ones; 2) the subject is treated as an active respondent, not a 'black box'; 3) the task is an identification one, not search-and-detect; 4) the whole natural saccade is provoked, as a part of a normally occuring oculomotor action (holistically). Subject-object interaction occurs during temporal microintervals, and is based on both previous and following gaze fixations, which we call *transsaccadic process*. Vision suppression is not what is being assumed, but the dynamic function response in time.

In presented study we assessed how presaccadic stimulus influences the intrasaccadic one. A comparison with other papers is held, involving primitive geometric objects but comparable optical and psychophysical conditions. Early papers on transsaccadic vision coincided with our results, although none of it was obvious unless directly compared by temporal structure and spatial characteristics.

Methods

The idea behind experiment is to separate and confront two naturalistically valid visual objects in one trial during attention switching to another point of interest. That effectively involves paracontrast, with one object (the lateral one) being a saccade target and the other (test), consistent in terms of content type, substitutes the first one during a saccade. Both peri- and intrasaccadic information cover same visual field areas, allowing for examination of their relation, including conditions affecting visual thresholds during this transitive process [1].

Apparatus. Our setup consisted of an SMI HiSpeed-1250 eyetracker and a PC running custom software for stimulus display.

Procedure. Subjects were told to perform a saccade from fixation cross to a lateral object, as soon as they notice the change. They were also told that they will be presented with an image of a human face, and their task is to assess its localization and identify the expression. The instruction given assumed they will be performing a reactive saccade, and did not allow to anticipate if there will be two expressions, or what it depends on.

At the beginning of every trial a fixation cross came out. The software checked for sufficient fixation being performed, and when its duration exceeds 3000 ms, the fixation cross is replaced with a lateral image, displaced either -10 or +10 dva horizontally (Fig. 1).

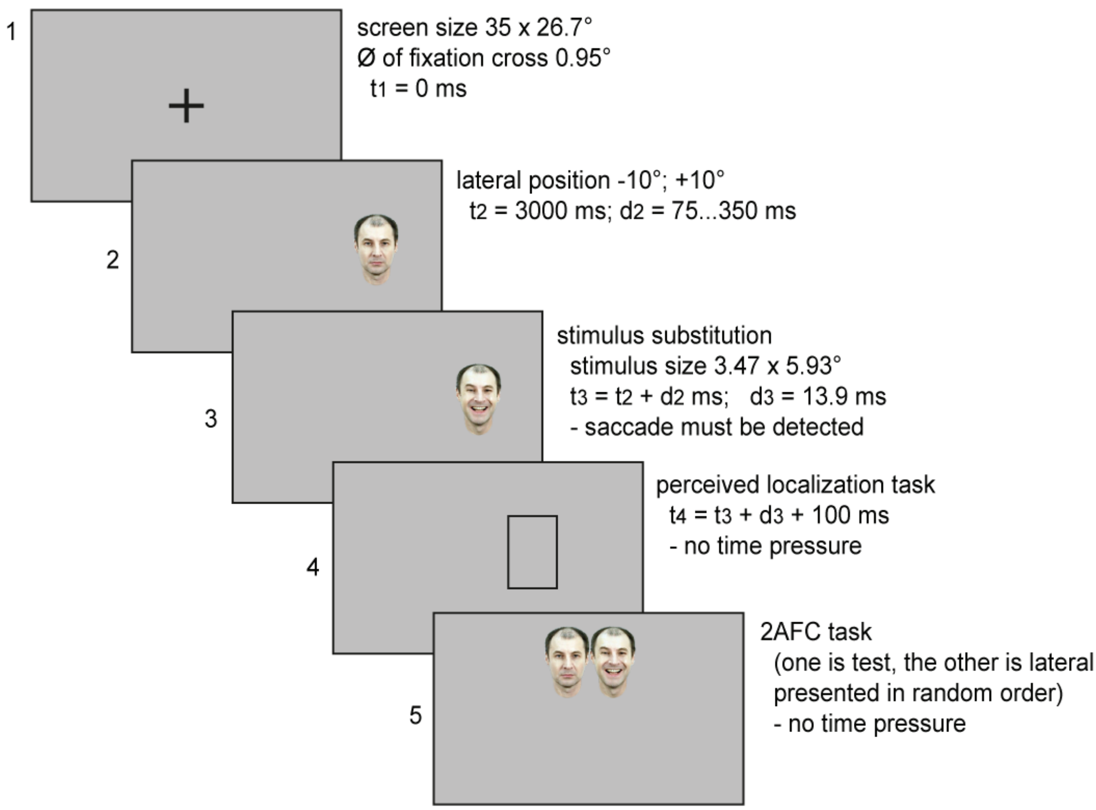

Fig. 1. Temporal layout for the experiment, with screen slices. Stimulus duration is annotated equal to 2 frames, respecting potential phosphorus decay time. Crosses and stimuli are not drawn to scale

The lateral object was represented by an image of facial expression, different from the one presented intrasaccadically. The beginning of a saccade triggered (although in-directly) simultaneous exposition of the test image (always with a duration of 1 display frame spanning 6.92 ms) and vanishing of the lateral one (because the test image was superimposed on top of it). The exact moment in time when this happened was registered with a photodiode sensor attached to a screen edge. 100 ms after the test image had disappeared, a rectangular frame was shown, which could be controlled with a mouse and constrained to horizontal only movement; after a click, two possible responses appeared, one depicting the test image, the other — the lateral one (both images were positioned either left or right from each other, chosen randomly, see Fig. 1, frag. 5).

The temporal layout is presented in Fig. 2. The procedure is similar to *temporal gap* paradigm, but image itself is the stimulus, not the gap, and there is an image substitution going on. Both tasks, perceived localization and perceived expression, were meant to be responded with a computer mouse. Keyboard usage was not required. Tasks were held at no time pressure.

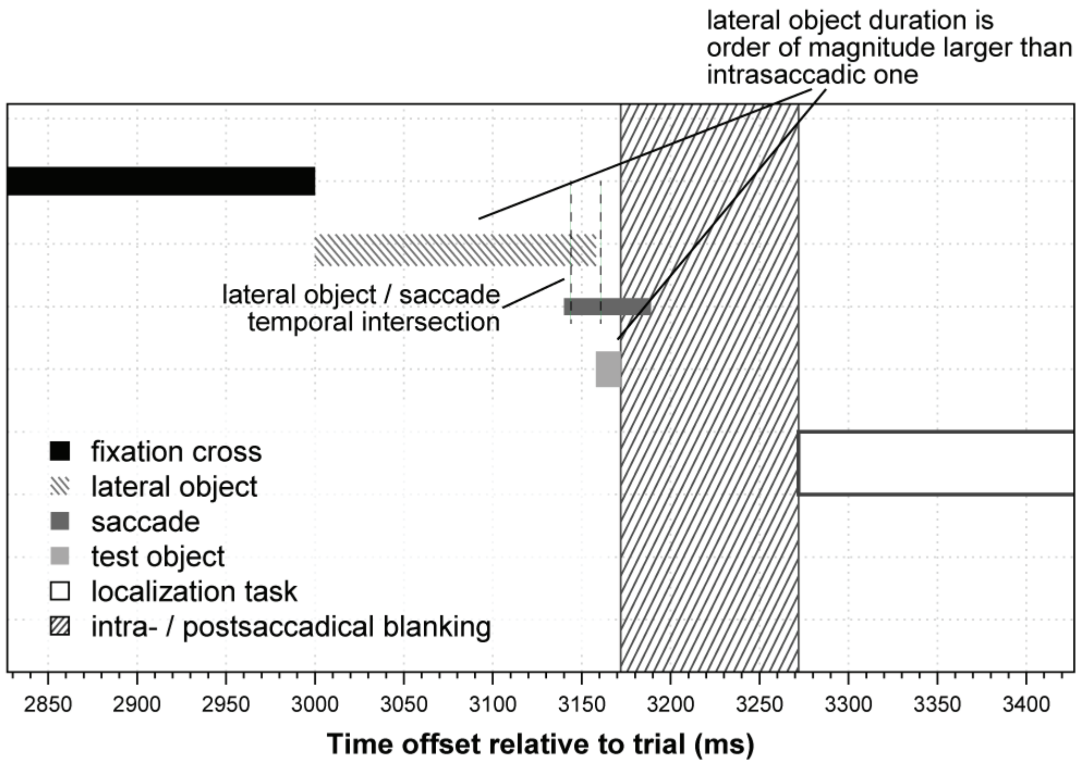

Fig. 2. Temporal layout of a trial. Lateral cross (saccadic target) vanishes before saccade offset, effectively providing for a postsaccadic target gap. The delay between stimulus offset and response menu appearance is 100 ms. Drawn saccade duration and latency are medians

Stimulus. Color images of a male face were presented randomly, depicting basic emotional expressions and a neutral one, taken from VEPEL image database [4]. Peak luminance 79.8 cd/m^2. Angular size 3.47 × 5.93 dva. Log relative luminance is 0.24.

Background is 75% gray, with luminance 46.3 cd/m². Dominant spatial frequency is 2 cpd (cycles per degree, horizontally).

Spatial frequency analysis was held by means of Gabor filters with different size and orientation. Fig. 3 shows original images with respective Gabor patches underneath, at four different angles (multiples of 45 degrees). Subjects were required to perform horizontal saccades, therefore, spatial frequency relevant for our study is for the vertical filter orientation (see Fig. 3, frag. 2). It can be seen that the dominant spatial frequency for this filter is 7 cpf (cycles per face, at eye level), which comprises 2 cpd (cycles per degree), given the angular size of the stimulus.

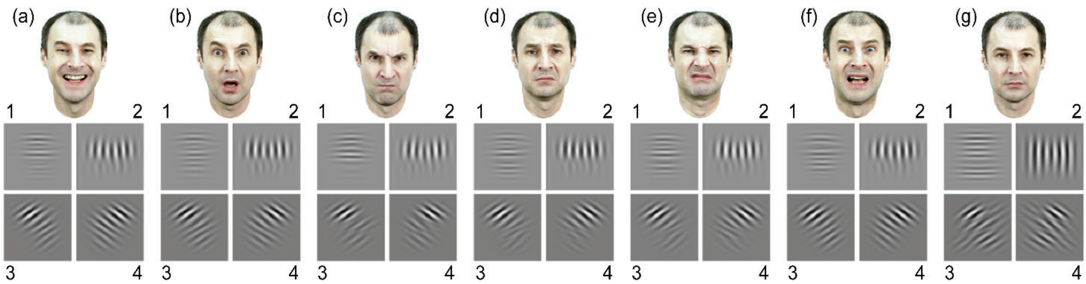

Fig. 3. Images used for stimulus (in color) with results of Gabor filtering. a — joy; b — surprise; c — anger; d — sadness; e — disgust; f — fear; g — neutral; 1 — horizontal filter; 2 — vertical filter; 3 — diagonal +45°; 4 — diagonal -45°

Data processing. Prior to statistical analysis, trials which failed to meet the requirements of the task were discarded, as following: latency of reactive saccade is not in range of 75—350 ms relative to lateral object onset; gaze position at stimulus onset was not >1,85° and <8,15° (absolute values) at stimulus offset (considering saccades have 10 dva amplitude); stimulus duration was longer than 2 display refreshes. Overall, 233 trials were rendered as valid (12% total).

Non-parametric criterion was used for inferential statistics, notably proportion test and chi-squared tests. Kolmogorov-Smirnov test was used for checking normality. t-test was used for metric data comparison. All tests were two-sided. Calculations were done in *R* statistical environment, version 4.0.2. Several external packages were used for plotting.

Sample. 21 subjects (9 female) were subject to analysis, with normal or corrected-to-normal vision. Median age is 22 ± 6 years.

Results

Eye movement statistics. During reactive saccades to the target object the following properties were observed: saccade latency 140±57 ms; saccade duration 46±11 ms; amplitude 8,6±1,3 dva; average velocity 183±36 dva/s; peak velocity 326±50 dva/s. Notably, saccade latency decreased by 44-66 ms (95% confidence interval) compared to the previous study, where a cross represented the lateral target [5]; t-test = 9.56(430) (degrees of freedom in braces, hereinafter); $p < 0.001$; Cohen's d=0.91 (large effect size); power=0.53.

Accuracy. No statistically significant identification rate of the intrasaccadic object was found (accuracy is 22%), chi sq. = 72.5(1); $p < 0.001$. Nevertheless, the lateral target is correctly identified above chance (accuracy is 78%). Fig. 4 shows F1 metric for identification rates. Correct identification is dependent on test-object expression; chi sq. = 32.96(6), p = 0.01; $\varphi_c = 0.18$ (small effect size); power=0.27; and also dependent on alternative expression (N.B. for the sake of analysis we assume lateral object is an alternative, and intrasaccadic one is a correct response); chi sq. = 47.74(6); p = 0.01; $\varphi_c = 0.26$ (small effect size); power=0.66. It is worth noting that participants were given instructions 'to choose the expression that you were presented with'. Intrasaccadic substitution was not mentioned, neither the fact there will be two images. They were let decide freely and interpret the stimulus as they wish.

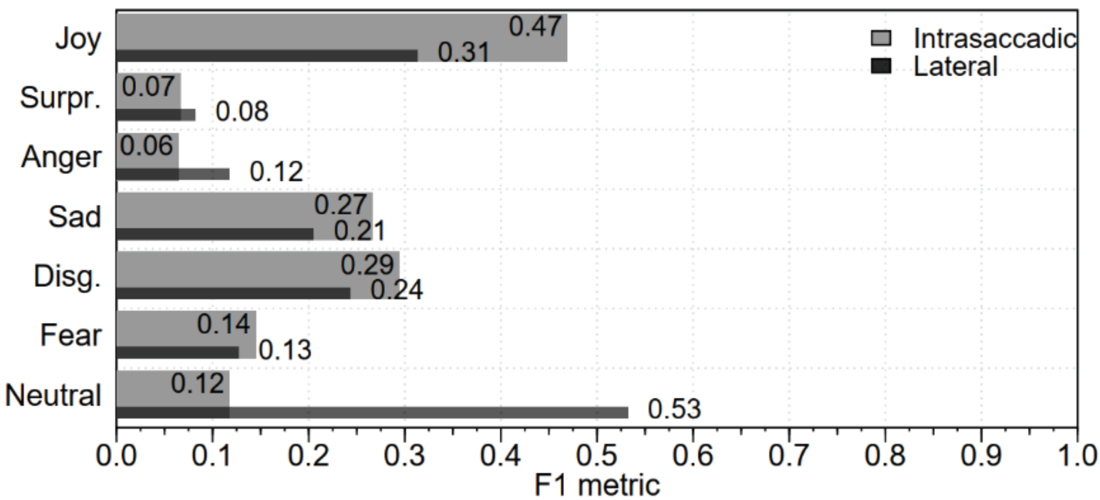

Fig. 4. Histograms for F1 metric of face expression identification. Lightgray thick bars depict F1 metric for correctly identifying the test object; darkgray thin bars depict F1 metric for correctly identifying it (any type of expression) in cases when that respective expression was an alternative one

When comparing results to paper published by Deubel, Schneider, Bridgeman (1996), considering their median saccade latency was 140 ms, our study matches by lateral object accuracy rates (the saccade *target*). Authors report that intrasaccadic object identification rate is minimized when temporal gap between it and the lateral one is near zero. This condition is satisfied by our design, except for the fact that lateral object had a much longer exposition duration (see Fig. 2). When latency equals 140 ms, accuracy rate is 82%. Notice that the only expression that fails to comply this notion is joy (if we invert the scale and assume lateral was the correct response), according to our results.

Relative responses. Data in Fig. 4 suggests that the least correctly identified expressions (thick bars) are not subject to process of integration with others, with intrasaccadic object being heavily masked. Even expression of joy remains at chance level. The better expression is identified, the more it potentially masks others. Notice neutral expression, when presented as alternative, boosts identification rates of the test object, while other expressions have mixed effect. Hereby, surprise and anger are preferred when presented as lateral (therefore, possess high attractiveness). However, both are rarely chosen when they represent the test object. It seems multiple factors are required for correct identification, which include, but are not limited by, type of expression and stimulus duration (and different minimum durations are inherent for various expression types). Moreover, base levels are not necessary equal to theoretical 0.5, which may indicate some transcendent factor (or conditions) impairing identification below statistical level of chance.

Identification mistakes. Fig. 5 represents structure of mistakenly chosen expressions as a chord diagram, under given conditions of intrasaccadic stimulus substitution. It suggests that joy possesses distinctive visual traits, preventing confusion caused by its visual attractiveness in those trials when it was a lateral object. On the contrary, the neutral expression has the least distinctive visuals, and is easily told apart if compared to the correct image; this is why it is rarely mistakenly chosen (no arrows point at it). Anger, surprise and sadness are the most frequent erratic responses.

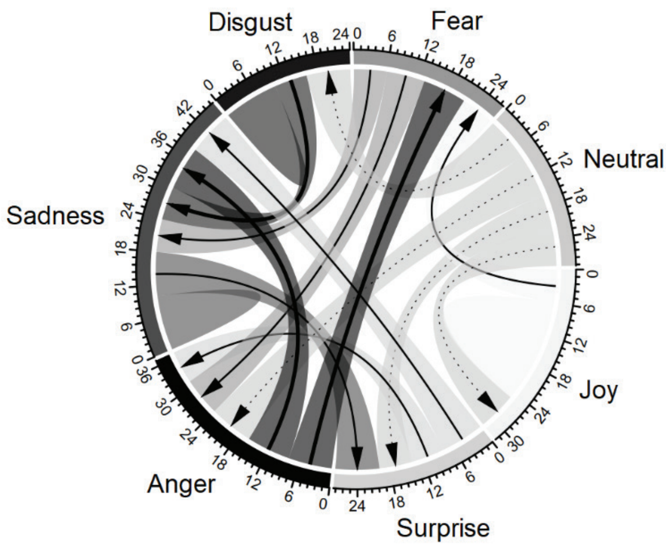

Fig. 5. Chord diagram for erratic identification of facial expressions. Arrows emerge from the test object expression, and point towards wrong response; solid humps represent percentage of correct responses for given expression. Radial scale shows absolute values. Least frequent mistakes are not shown for clarity

Perceived locations. Because both lateral and intrasaccadic objects were presented in same location (Fig. 1, frag. 2,3), space compression effect was neither expected nor actually observed. Although a minor tendency towards *extension* of perceived distance is present, there was not enough statistical power to prove that. In general, intrasaccadic stimulus substitution did not cause inadequate perception of location. Let us emphasize once again, that both object of perception and its location was interpreted and chosen (from either the lateral one, lasting more than 100 ms, or the intrasaccadic one, lasting less than 15 ms) by participants arbitrarily.

Discussion

Summarizing the findings, we note the following. When stimulus definition is ambiguous, allowing for voluntary identification of images presented in rapid sequence, the first one is preferred 3.5 times more often. Respecting the fact that lateral object had almost 10 times larger duration, it is easily attributed to forward masking effect. The novelty is brought in by procedure, involving peripheral exposition (±10 dva) of the lateral image, and intrasaccadic exposition of the test image. Considering the issue under discussion, that means presaccadic object of perception influences data perceived during saccades, tremendously decreasing visual sensitivity.

Required condition for the masking effect to occur is the homogeneity of lateral and intrasaccadic stimuli. As was reported previously [5], the lateral cross (less than 1°) does not impair identification of facial expressions presented during saccades. Remarkably, facial expression also yields shorter saccade latencies, which indicates more *perceptual environment complexity* effect.

Although identification rates are below chance, they remain consistent. Trends discovered in previous studies remain (where a lateral cross was a saccade target), although to a lesser extent: expression identification rate, structure of wrong responses (false positives), statistical dependency on type of alternative expression, and saccade psychophysical properties (except for the latency). This indicates key determinants of transsaccadic process are retained, and its ultimate outcome is indeed subject to forward masking effect.

After conducted analysis, we need to discuss saccadic suppression and what causes it. Based on the data acquired, on the level of significant events perception, visual sensitivity decline during saccades does not require us to assume a separate physiological mechanism for that, responsible for temporarily fragmenting the visual process. Combining certain conditions is enough, and each of them leads to impaired facial expression identification. There are few of them: (1) ultrashort duration of test object exposition, (2) its peripheral location, (3) masking effect caused by the lateral face image, (4) similarity of facial expressions both at trial-time and response-time intervals. Besides those, there are some additional conditions to take into account: (5) true location of the masking object and the test image match, (6) the rectangular frame displayed for perceived location task may potentially cause metacontrast. No standard for correct identification of facial expression exists. This is rather an operational issue emerging during each environmental condition separately, with current behavior requirements taken into consideration. Based on that, levels and concentration vector are tuned. That said, it is possible to raise transsaccadic sensitivity by excluding the (meaningful) masking object to a certain level, but limited by interaction of other factors [34].

Same findings stand true for most of psychophysical studies of transsaccadic perception, except for the fact that saccadic suppression is considered a paramount factor.

Visual perception of subthreshold duration stimuli depends on angular size, relative luminance, local contrast, spatial frequency ratio of background to the object, and how they are related. Significance of backward masking (metacontrast) for saccadic suppression was discovered by MacKay (1972). According to forward and backward masking curves, acquired by Crawford (1947, p. 286), the maximum masking effect (1.9—3 log units) is observed if mask is in temporal proximity to stimulus of 0 to +80 ms. Absolute absence of masking is observed if temporal proximity equals -10 — -20 ms (i.e. backward masking). This data was acquired for 10 ms stimulus and 524 ms mask (as it is known, metacontrast effect intensifies when the mask is brighter and temporally longer), with 0.5 dva stimulus size. Those parameters have been sufficiently satisfied by our study: the test object is presented 10-15 ms before saccade offset, after which perceptual transition is usually over, and multiple natural maskers emerge. But appearance of a new intrasaccadic object supports visible environment constancy, and helps track attention on the object. Lack of any structured background (as in experimental studies) during saccade offset facilitates the data acquired during saccade to be reacquired and analysed normally, like during fixation.

If compared to other papers, it becomes apparent that no other study used a stimulus with such a low relative luminance as we did [3], except those which have reported strong suppression [21; 31]. Nevertheless, our study is not the only one to report identification rate above chance during saccades. Given a sufficient angular size of stimuli (while keeping spatial frequency inside a specific range of 1.8-3 cpd), object detection becomes possible. It is important that exposition duration stays small, and does not intersect saccadic temporal boundaries. Some researchers conclude that minimum saccadic suppression can be achieved by presenting low-frequency spatial gratings (<1 cpd), whereas it is usually maximized with highly structured background [26; 32; 35]. We need to accentuate that geometric primitive shapes used earlier (gratings, flashes) have much higher spatial frequency (5 — 8 cpd; [12; 31]), than our facial expression images with given angular size (2 cpd). Notably, contrast sensitivity [15] and chromatic differentiation [27] are maxed out on that particular spatial frequency of 1.7-2.0 cpd. Burr, Morrone, Ross (1994) conclude that saccadic suppression is most probable at spatial frequency band of 0.2-0.8 cpd, whilst the band of 2.0-10.0 cpd is virtually never suppressed.

Previous findings have shown most trials have sensitivity begin decreasing at approximately -40 — -20 ms range *before* saccade onset, with an absolute minimum at saccade onset itself [3], i.e., matching the latency interval. Further on, sensitivity is not suppressed, but grows smoothly while saccade is running, *restoring* its initial sensitivity level. That possibly means saccadic suppression is not caused by the saccadic process itself, but the preparation stage, involving attention transition process and visual field transformation. We are talking about reformatting perceived environment, which is often accompanied by space compression effect with a gradient rising towards the new object of attention, redistribution of visual acuity and object differentiation, programming of upcoming saccadic movement, and, finally, translation of observer's imaginary location. The study presented currently have found no signs of saccadic suppression so far, which could potentially occurred if no forward masking was observed, compared to previously conducted experimental runs.

Also, some drastically important differences were caused by the specifics of the procedure. *Two levels* of transsaccadic perception manifested: sensoric and gnostical. The former is related to stimulus detection by its optical or geometric primitives, the latter one — with the identification itself, and classifying the stimulus as belonging to a certain category. Both processes are tightly coupled together in everyday life, constantly blending with each other. Sensoric tasks are dominantly based on inherent mechanisms of visual perception, and characterize energy related issues or spatiotemporal parameters of the stimuli. Gnostical tasks are more difficult, demand previous experience and require that subject already has some attitude towards the object of perception. Laws of sensoric perception also exist on gnostical level, but are somewhat modified. Presented studies revealed higher accuracy rates and lower response variability for facial expressions. Suppression effect reported earlier for detection of primitive objects is not retained for naturalistically valid stimulus. Unlike geometric shapes and light flashes, facial expression identification rate is above chance for each time interval in perisaccadic range, and is almost on par with perception on a day to day basis.

Therefore, presaccadic stimulus provoking saccade is in fact responsible for intrasaccadic sensitivity decrease, provided both stimuli are from the same category. The forward masking effect shown eliminates potential saccadic suppression, imminent for primitive shape objects. Transsaccadic perception has layered structure and obeys a common temporal schema. Dependency of visual function on internal and external conditions provides a reason to look for such permutations which yield the best intrasaccadic sensitivity possible. This makes it promising to find application for visual data obtained during rapid eye movements in man.

Conclusion

In summary, the data obtained supports the ability to correctly perceive complex, naturalistically valid objects during saccades, and describes the conditions necessary for this process to succeed. We have conducted an experimental run of facial expression identification and registered presaccadic data interfering with intrasaccadic one (forward masking effect). Basic trends reported by us previously are reproduced, but in reduced form, such as: identification rates for facial expressions, structure of wrong responses, dependency on the alternative expression type, saccade properties, etc. Both lateral and test objects should be homogeneous in terms of stimulus category and, most likely, psychophysical properties (luminance, spatial frequency, angular size and others). Reactive saccade latency tends to be smaller when saccade target is also a face. There was no saccadic suppression observed, although it is traditionally considered a fundamental phenomenon for visual detection studies (of most basic psychophysical properties). Comparative analysis of data obtained under different conditions creates notion of two levels of transsaccadic perception — sensoric and gnostical, sharing common temporal structure. Visual perception at pre-, intra- and postsaccadic intervals is relying on visual environment retagging once a new object of interest is detected. Saccades separate visual information stream into their own microfragments, but also combine them for continuous perception. Visual perception is both discrete and perpetual at the same time.

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