ARTICLE IN PRESS

Cognition xxx (2012) xxx–xxx

Contents lists available at SciVerse ScienceDirect

Cognition

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

Brief article

Environmental inversion effects in face perception

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A R T I C L E   I N F O

Article history:
Received 3 December 2011
Revised 22 February 2012
Accepted 23 February 2012
Available online xxxx

Keywords:
Inversion effect
Reference frames
Embodiment
Face perception
Memory

A B S T R A C T

Visual processing is highly sensitive to stimulus orientation; for example, face perception is drastically worse when faces are oriented inverted vs. upright. However, stimulus orientation must be established in relation to a particular reference frame, and in most studies, several reference frames are conflated. Which reference frame(s) matter in the perception of faces? Here we describe a simple, novel method for dissociating effects of egocentric and environmental orientation on face processing. Participants performed one of two face-processing tasks (expression classification and recognition memory) as they lay horizontally, which served to disassociate the egocentric and environmental frames. We found large effects of egocentric orientation on performance and smaller but reliable effects of environmental orientation. In a follow-up control experiment, we ruled out the possibility that the latter could be explained by compensatory ocular counterroll. We argue that environmental orientation influences face processing, which is revealed when egocentric orientation is fixed.

1. Introduction

We live in a world that is highly structured by spatial regularities. For example, living organisms tend to display horizontal symmetry in their physical attributes and their movements are constrained by the directional pull of gravity. Many human behaviors are sensitive to this structure; spatial regularities can guide attention in a scene (Chun & Jiang, 1998), facilitate responses in visual search (Kunar, Flusberg, Horowitz, & Wolfe, 2007), and bias our interpretation of ambiguous objects (Rock, 1973). A well-studied phenomenon in this domain is the impact of the *orientation* of a stimulus on our ability to perceive and remember it (Rock, 1973; Tarr, 1995). Nowhere is the role of orientation more apparent than in face processing; across a range of perception and memory tasks, observers show markedly worse performance when faces are presented upside-down as compared to upright (*face inversion effect*; Collishaw & Hole, 2002; Davidenko, 2007; Goffaux & Rossion, 2007; McKone, 2004; Rhodes, Brake, & Atkinson, 1993; Thompson, 1980; Yin, 1969), whereas sideways (90°) faces generally elicit intermediate performance (Valentine & Bruce, 1988; Jacques & Rossion, 2007; but see Schwaninger & Mast, 2005).

However, understanding the role of spatial orientation in perception is complicated by the fact that stimulus orientation can be defined in relation to various different reference frames. For example, the orientation of a face may be described with respect to an observer's eyes, head, or body orientation (*egocentric* reference frames). At the same time, the orientation of a face may also be described with respect to the room it is located in or the directional pull of gravity (*environmental* reference frames). In relation to which reference frame(s) do we perceive faces?

This question is difficult to answer based on the existing literature because egocentric and environmental reference frames are usually conflated in experiments investigating orientation effects in face perception (but see Chang, Harris, & Troje, 2010; Troje, 2003; and Discussion). Typically, participants perform face perception tasks while seated in front of a computer, where stimuli that are upright in relation to a participant's eyes and head are also upright in the environment. Although research in other

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doi:10.1016/j.cognition.2012.02.009

Please cite this article in press as: Davidenko, N., & Flusberg, S. J. Environmental inversion effects in face perception. *Cognition* (2012), doi:10.1016/j.cognition.2012.02.009

domains has shown that both egocentric and environmental orientation can influence the perception of scenes, objects, and bodies (Chang et al., 2010; Kelly & McNamara, 2008; Lopez, Bachofner, Mercier, & Blanke, 2009; Rock, 1973), to date there is no evidence that environmental orientation has an influence in our ability to process faces.

Here we describe a simple, novel method for investigating potentially independent effects of egocentric and environmental reference frames in face perception. Participants performed face-processing tasks while lying horizontally, thereby disassociating the egocentric and environmental orientation of stimuli (see Fig. 1). When observers lie horizontally, faces presented upright or inverted in the egocentric frame are rotated by 90° in the environmental frame, whereas faces presented upright or inverted in the environmental frame are rotated by 90° in the egocentric frame. This allows us to measure inversion effects in each reference frame while keeping orientation in the alternative frame constant at 90°.

2. Materials and methods

2.1. Experiment 1

In relation to which reference frame(s) do inversion effects for faces occur? Participants completed one of two face-processing tasks while lying on their sides with their heads fixed horizontally. In Experiment 1a, participants classified the emotional expression of two-tone "Mooney" faces (McKone, 2004; Mooney & Ferguson, 1951). In Experiment 1b, participants performed an old/new recognition memory task on front-view, gray-scale face images.

2.1.1. Participants

Eighty-two individuals from the Stanford community were recruited to participate in either Experiment 1a or 1b in exchange for payment or class credit.

2.1.2. Apparatus

Participants performed the tasks while lying on a padded bench in a brightly lit experiment room. A leveled, horizontally mounted head and chin rest with head-strap was constructed in-house to maintain participants' heads fixed horizontally (see Fig. 2). Stimuli were displayed on a 15″

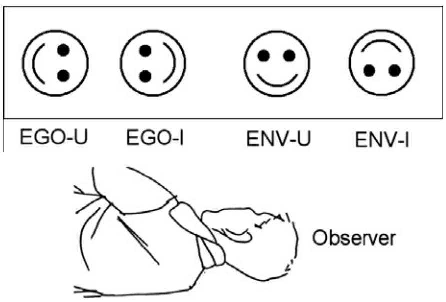

Fig. 1. Schematic of an observer lying horizontally while observing images in four possible orientations. EGO-U: egocentrically upright; EGO-I: egocentrically inverted; ENV-U: environmentally upright; ENV-I: environmentally inverted.

Fig. 2. A person fitted in the horizontally mounted head and chin rest with head strap holding a response pad as used in Experiment 1a.

Macbook Pro which was placed on a flat horizontal surface and positioned approximately 33 cm from participants' eyes. At this distance, the face stimuli subtended 5° × 7° of visual angle. To maximize our chances of discovering an effect of the environmental reference frame on face perception, the setup provided participants with multiple cues to environmental orientation, including proprioceptive cues to the directional pull of gravity, as well as visual cues like the display screen, the surrounding desk, and the walls of the experiment room.

2.1.3. Stimuli and procedure: Experiment 1a

Fifty-six participants were randomly assigned to Experiment 1a. Mooney faces were generated by blurring grayscale photographs and reducing them to two tones (see Supplementary materials A). We selected 48 faces that could be easily identified as happy (16), sad (16), or angry (16) when viewed upright. We then mirror-reversed each of these to create a total of 96 Mooney faces (see Fig. 3a).

The expression classification task was programmed in Matlab using PsychToolbox3 (Brainard, 1997). In each trial, a single Mooney face was presented at the center of the display on a black background. Participants held a keypad in their left hand and classified the emotional expression of the face by pressing one of 3 keys corresponding to "happy," "sad," or "angry," using three fingers on their right hand. Faces remained on the screen until participants responded.

After completing eight practice trials while seated upright at a desk, participants were randomly assigned to lie down on their right or left side, after which the experimenter fitted them into the head and chin rest. Mooney faces were randomly assigned to appear in one of four possible orientations – egocentrically upright (EGO-U), egocentrically inverted (EGO-I), environmentally upright (ENV-U), and environmentally inverted (ENV-I; see Fig. 1). After classifying the expressions of 48 Mooney faces while lying on one side, participants were instructed to lie on the opposite side and the experimenter re-fitted them into the head rest. Participants then performed another 48 expression classifications of the mirror-reversed

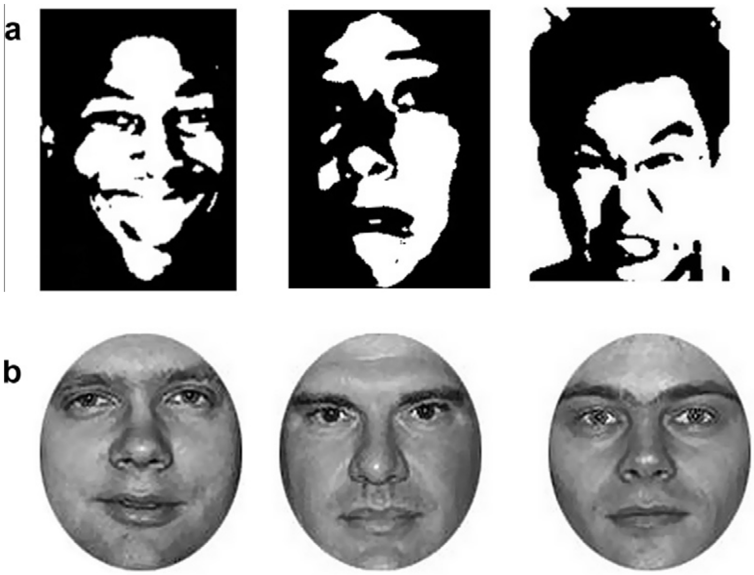

Fig. 3. Example stimuli. (a) Mooney faces (happy, sad, and angry) for Experiment 1a; (b) normalized gray-scale faces for Experiment 1b.

Mooney faces, each appearing in a new random orientation. No feedback was given.

2.1.4. Stimuli and procedure: Experiment 1b

Twenty-six participants were randomly assigned to Experiment 1b. One hundred and ninety two gray-scale photographs of Caucasian males were selected from the FERET database (Phillips, Wechsler, Huang, & Rauss, 1998). Stimuli were cropped using an oval shape to remove hair and clothing around each face and normalized for size, brightness, and contrast (see Fig. 3b).

The old/new recognition task was programmed in Matlab using PsychToolbox3. Participants completed four study/test blocks while lying on one side and four study/test blocks while lying on the opposite side. The order of body positions was randomized across participants.

During each study block, a sequence of 12 different faces in a single orientation (e.g., all EGO-U) was presented four times in random order. Each image remained on the screen for 900 ms with a 100 ms inter-stimulus interval (ISI). The background of the display was black.

A test block immediately followed each study block. The 12 studied faces along with 12 unstudied faces were presented in random order, in the same orientation as in the study block. Participants held a computer mouse in their right hand and indicated whether each face was "old" (left button) or "new" (right button). Test images remained on the screen until participants provided a response. No feedback was given.

2.2. Experiment 2

Experiment 1 was intended to measure whether there were independent effects of egocentric and environmental orientation on face processing. However, our design assumed that when participants lay sideways in our apparatus, both ENV-U and ENV-I face images were rotated by the same amount (90°) in participants' egocentric reference frames. Although our apparatus maintained participants' heads and bodies fixed at 90°, it did not precisely constrain the orientation of participants' eyes. In fact, when we tilt our heads in one direction, our eyes exert a small automatic compensatory ocular counter-roll (OCR; see Supplementary materials B) of several degrees in the opposite direction (Misslisch, Tweed, & Hess, 2001; Sares, Granjon, Abdelrhani, & Boulinguez, 2007). In our experiment, OCR would cause participants' retinal (eye-centered) frame to be slightly more aligned to ENV-U than ENV-I faces. To address this possibility, in Experiment 2 we first measured OCR for each participant ($N = 26$) as they lay horizontally by use of a flash/after-image technique (mean OCR across participants = 4.0°, SD = 3.5°; see Supplementary materials C). We then adjusted our apparatus to correct for each participant's OCR (see Supplementary materials D).

2.2.1. Participants

Twenty-six individuals from the Stanford community were recruited to participate in Experiment 2 in exchange for payment or class credit.

2.2.2. Stimuli and procedure

Experiment 2 was nearly identical to Experiment 1, except: (1) the head rest apparatus was rotated to compensate for each participant's OCR to the nearest 0.5° (see Supplementary materials C), (2) faces appeared only in ENV-U and ENV-I orientations, and (3) participants performed the tasks while lying on their right side only. Participants first completed two study/test blocks of the recognition memory task and then classified the emotional expressions of 96 Mooney faces.

3. Results

3.1. Experiment 1a

Data from 6 participants were excluded from analysis because they failed to perform above chance ($n = 1$) or their median RT was more than three standard deviations above the group median ($n = 5$). Results of a 2-way ANOVA (2 body positions × 4 image orientations) showed no main effect of body position ($F(1,49) = 1.40$, $p > 0.2$) and no interaction between body position and image orientation ($F(1,49) = 1.59$, $p > 0.2$). We therefore collapsed each participant's data across the two body positions. An *egocentric inversion effect* would manifest as better performance in EGO-U vs. EGO-I trials. An *environmental inversion effect* would manifest as better performance in ENV-U vs. ENV-I trials.

For each participant, we computed proportion correct (PC) and median response time (RT) on correct trials. PC was significantly above chance (1/3) for all image orientations ($ts(49) > 16$, $p < 10^{-20}$). As expected, we observed a large egocentric inversion effect, with higher PC (0.94 vs. 0.70) and faster RT (917 ms vs. 1160 ms) for EGO-U vs. EGO-I faces (PC: $t(49) = 15.6$, $p < 10^{-19}$; RT: $t(49) = -9.3$, $p < 10^{-11}$; see Fig. 4a). Intriguingly, we also found a reliable environmental inversion effect: responses were more accurate (0.843 vs. 0.796) and faster (1039 ms vs. 1084 ms) for ENV-U vs. ENV-I faces ($t(49) = -2.4$, $p < 0.05$ for each measure; see Fig. 4a).

3.2. Experiment 1b

Data from 1 participant were excluded from analysis because they failed to perform above chance levels on the recognition task. A 2-way ANOVA showed neither a main effect of body position ($F(1,24) = 0.35$, $p > 0.5$) nor an interaction between body position and image orientation ($F(1,24) = 1.34$, $p > 0.1$). Therefore, as in Experiment 1a, we collapsed each participant's data across the two body positions.

We measured participants' ability to discriminate old from new faces (d') and their median RT on correct trials. Across participants, we found a large egocentric inversion effect: discrimination ($d' = 1.47$ vs. 0.64) and RT (976 ms vs. 1112 ms) were better for EGO-U compared to EGO-I trials (d': $t(24) = 5.44$, $p < 0.0001$; and RT: $t(24) = -3.49$, $p < 0.01$). In addition, we found a significant environmental inversion effect: d' was higher for ENV-U faces than ENV-I faces (1.00 vs. 0.76; $t(24) = 3.0$, $p < 0.01$). RTs were non-significantly faster for EGO-U (1052 ms) than EGO-I (1096 ms) faces ($p = 0.3$), ruling out a speed-accuracy trade-off (see Fig. 4b).

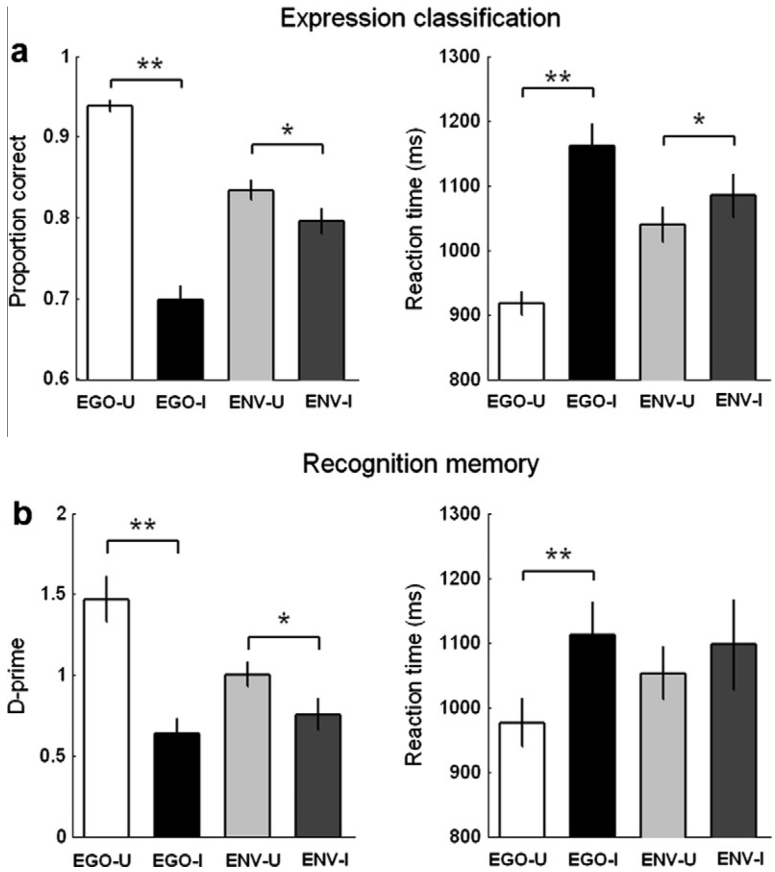

Fig. 4. Results of Experiment 1. (a) Proportion correct (left) and RT (right) in the expression classification task (chance performance was 1/3; $N = 50$). (b) D-prime and RT in the recognition memory task ($N = 25$). Error bars denote between-subjects SEM. $^{*}p < 0.05$ (paired t-test, 2-tailed); $^{**}p < 0.001$.

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3.3. Experiment 2a and 2b

Data from 2 participants in Experiment 2a (expression classification) were excluded from analysis because their RTs were more than three standard deviations above the median, and data from 3 participants in Experiment 2b (recognition memory) were excluded because they failed to perform above chance levels. Even after compensating for OCR (thereby ensuring that the retinal orientation of images was 90° in both the ENV-U and ENV-I conditions), we found significant environmental inversion effects in performance in both tasks. In Experiment 2a participants were significantly better at classifying ENV-U (PC = 0.83) than ENV-I (0.80) Mooney faces ($t(23) = 2.54$; $p < 0.05$; see Fig. 5a). In Experiment 2b, participants were significantly better at recognizing ENV-U ($d' = 1.11$) vs. ENV-I (0.81) gray-scale faces ($t(22) = 3.19$; $p < 0.01$; see Fig. 5b). In both tasks, median RTs were non-significantly faster during correct ENV-U than ENV-I trials, ruling out a speed-accuracy trade-off.

4. Discussion

In two very different face perception tasks, we have shown that when participants lie horizontally, they are better at processing (1) egocentrically upright vs. inverted faces, and (2) environmentally upright vs. inverted faces. While the importance of egocentric (especially retinal) orientation in face perception is well established (e.g., Rossion, 2008; Troje, 2003), the results of Experiment 1 provide the first evidence for an influence of environmental orientation in face processing. In Experiment 2, we showed that these results cannot be attributed to an OCR-induced asymmetry in retinal orientation across the two environmental orientation conditions. We conclude that there are reliable effects of environmental orientation in face processing that are revealed when observers lie horizontally and egocentric orientation is fixed at 90°.

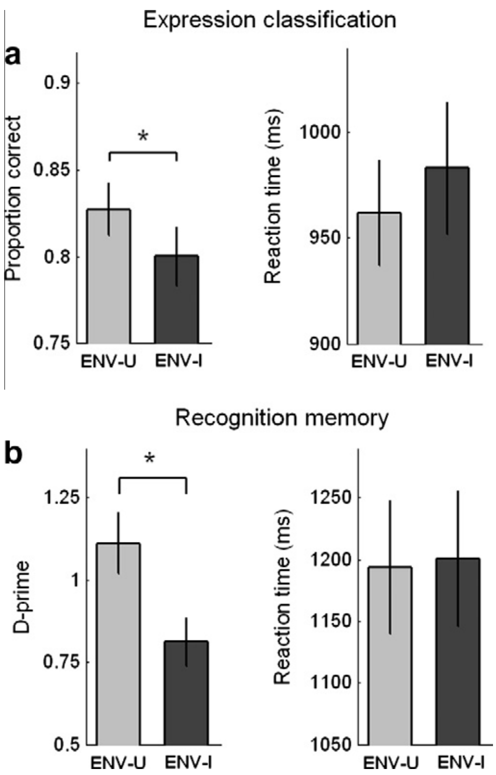

Fig. 5. Results of Experiment 2, compensating for OCR. (a) Proportion correct (left) and median RT (right) in the expression classification task (Experiment 2a; $N = 24$). (b) D-prime and RT in the recognition memory task (Experiment 2b; $N = 23$). Error bars denote between-subjects SEM. $^{*}p < 0.05$ (paired t-test, 2-tailed).

Interestingly, our results appear at odds with some recent research that sought but failed to find reliable effects of environmental orientation on face perception (Chang et al., 2010; de Schonen, Leone, & Lipshits, 1998; Lobmaier & Mast, 2007; Troje, 2003). There are several differences across these experiments that may explain the diverging results. Troje (2003) pitted observers' egocentric and environmental reference frames against one another, either by having observers tilt their heads by 90° or by rotating face stimuli by 90° (or both). Troje's results showed only a main effect of egocentric orientation on performance in a sequential same-different face recognition task. Given that our data reveal a much larger egocentric than environmental inversion effect (see Experiment 1, Fig. 4), we suggest that a large effect of egocentric orientation in Troje's study may have masked a smaller effect of environmental orientation. Similarly, work by de Schonen et al. (1998) and Lobmaier and Mast (2007) measured whether the size of the egocentric inversion effect for faces was modulated by environmental orientation, and found weak or no influence. We note that in our studies, the influence of environmental orientation was only evident when egocentric orientation was fixed at 90° and environmental orientation was either upright or inverted, which neither of the above studies compared. Finally, Chang et al. (2010) investigated face and biological motion perception using a rotating experiment room, which allowed them to independently manipulate stimulus orientation with respect to egocentric, visuo-environmental, and gravitational reference frames. They did not find reliable effects of environmental orientation on face processing (although they did report non-significant trends in the same direction as our data). We suggest that Chang et al.'s (2010) experimental paradigm, which compared performance across 24 different conditions (crossing body, room, and stimulus orientations), may have lacked the statistical power to detect a difference between the two critical conditions we isolated in our study. In addition, our experiments utilized particularly challenging face perception tasks, while Chang el al. (2010) used a simpler sequential same-different face recognition task. It may be that environmental inversion effects are only measurable in tasks that require detailed configural or holistic processing, a possibility that was raised by Chang and colleagues (page 8; also see Goffaux & Rossion, 2007; Riesenhuber & Wolff, 2009; Rossion, 2008).

It is worth noting that in our experiments, we intentionally made multiple cues to environmental orientation available to participants. For example, ENV-U faces were upright with respect to the computer screen, the surrounding walls of the experiment room, and the directional pull of gravity. Previous work (e.g., Chang et al., 2010) that dissociated multiple cues to environmental orientation by the use of a rotating experiment room found that gravitational (rather than visual) cues affect the perception of biological motion, suggesting the same might be true in the domain of face perception. However, a study performed in microgravity (de Schonen et al., 1998) found that the magnitude of the egocentric face inversion effect was not influenced by the presence or absence of gravitational cues. It therefore remains a question for future research to examine whether environmental inversion effects in face processing can be attributed to visual cues, gravitational cues, or both.

Our studies extend previous work that examined the sources of inversion effects in high-level perception: in addition to *egocentric* effects (Chang et al., 2010; Troje, 2003), and *allocentric* (object-centered) effects (Goffaux & Rossion, 2007), we have now demonstrated *environmental* effects on face perception and memory. Our findings have implications for the design of future experiments, suggesting that researchers should be aware of potential effects of environmental orientation on face processing. For example, in some experiments, participants may be positioned differently between study and test sessions (e.g., when one session takes place inside an fMRI scanner), and this may impact performance in ways the experimenters did not originally intend.

What mechanisms might underlie an environmental inversion effect in face processing? We likely learn from experience that certain stimuli tend to appear upright in the world, regardless of our own body's position when we observe them. For example, we may lie sideways when watching television, but nevertheless faces on the screen remain upright in relation to the television set, the room, and the directional pull of gravity. Faces we encounter when we tilt our heads throughout the day are also more likely to be upright than inverted in the environment. We propose that when visual stimuli are reliably encountered in a particular orientation relative to a given reference frame (or multiple reference frames), these regularities form an integral part of our visual representations.

Acknowledgments

The authors thank Jason Loftus for help with data collection and Harry Bahlman for engineering our experimental apparatus. We thank Nathan Witthoft and Martin Banks for helpful suggestions about OCR and its measurement. We also thank Alexia Toskos Dils, Adriana Weisleder, Jon Winawer, Daniel Sternberg, Helen Tager-Flusberg and Lera Boroditsky for comments on our studies and on earlier drafts of the manuscript. This work was supported by NRSA Postdoctoral Fellowship 1F32EY018279 to N.D.

Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.cognition.2012.02.009.

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