THE ROLE OF NEURAL CIRCUITRY IN ASSESSING THE VALUE OF SOCIAL INFORMATION

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ABSTRACT

Decisions motivated by primary rewards such as food, and abstract rewards such as money, follow several general principles. Such rewards are discounted as time passes. Not surprisingly, discounting decreases as the size of the offer increases and is greatest during initial stages of delay until reward consumption. Although behavioral and neurobiological evidence suggests that people find looking at other people rewarding, it remains unknown whether these same neuroeconomic principles underlie visual orienting decisions in social contexts. To address this question, we assessed the reward value of looking at photographs of unfamiliar members of the opposite sex. We found that viewing images of people followed the principles of other primary and abstract rewards. Specifically, the opportunity to view pictures of the opposite sex was discounted temporally in an intertemporal choice task. In addition, the reward value for male participants varied with the physical attractiveness of the females in the image set. However, this effect was not seen with female participants. These results demonstrate that social attention follows a general set of neuroeconomic principles, thus implicating shared neural mechanisms in both social and nonsocial decision-making.

INTRODUCTION

Adaptive social behavior clearly benefits from information about other individuals. Strategically beneficial information may include a rival's fighting ability or the likely genetic fitness of a potential mate. Humans display a strong desire to discern information about other individuals. In fact, many studies have revealed that people preferentially look at the faces of others in photographs and movies and such preferences emerge early in infancy (Morton and Johnson, 1991). Viewing preferred faces activates specific brain structures including the ventral striatum and orbitofrontal cortex (Aharon et al., 2001), the same structures that respond to rewards such as food and money (Winston et al., 2007). Moreover, disruptions of these structures result in an inability to process the normal valuation of social stimuli and may contribute to the dysfunctional social behavior seen in neurological disorders such as autism, social anxiety, schizophrenia, and anorexia (Klin et al., 2002; Frith, 2001; Birbaumer et al., 1998; Adolphs, 2003; Baron-Cohen and Belmont, 2005; Pelphrey et al., 2002; Langdon et al., 2006; Whittaker et al., 2001; Deldin et al., 2000). These results suggest that humans increase their likelihood of survival by discerning information about other individuals.

The fact that viewing preferred faces, and obtaining food, drink or money, all activate the ventral striatum and orbitofrontal cortex suggests that viewing other individuals serves as a reward. If so, then the opportunity to see another person should follow the same principles that guide decision-making motivated by monetary or appetitive rewards. A wealth of research in neuroeconomics and experimental psychology has identified several core characteristics of appetitive and monetary rewards. For instance, both humans and animals "discount" anticipated rewards as time passes between realization and receipt of the reward (Mazur, 1987). In other words, as the delay increases, the desire to obtain the reward decreases. When faced with an option to receive a small reward immediately or a larger reward after a given amount of time, the smaller reward may be chosen through discounting. It has been shown that monetary offers are discounted most strikingly during the initial stages of delay (Giordano et al., 2002). For example, if one must wait one year until receiving a million dollar reward, the relative value of the reward may decrease to only $500,000. In other words, if faced with the option of receiving $500,000 immediately or $1,000,000 after one year, the immediate option may be chosen. However, waiting an additional year might decrease the relative value of the initial reward less dramatically, perhaps to $350,000. Therefore, the value of the reward decreases by 50% in the first year, but by only 30% in the second year. The phenomenon of discounting appears to be less pronounced with smaller rewards (Mazur, 1987). If the initial reward was only $100, its relative value may decay by only 10% in the first year and 5% in the second year.

Almost nothing is known about how we evaluate the opportunity to look at another person. However, understanding the neural mechanisms which govern this evaluation could be very useful in studying social disorders such as autism. One reasonable hypothesis is that social orienting decisions follow the same neuroeconomic principles as those governing the valuation of rewards such as food, drink, and money. To test this idea empirically, we investigated whether people discount the opportunity to view photos of other people. In particular, we wondered whether reward value (e.g. the opportunity to view more attractive people or to view people for a longer amount of time) influences an individual's discount rate. We found that social orienting decisions obey principles remarkably similar to those underlying neuroeconomic choices about food or money, suggesting a shared neural system that mediates both social and non-social decision-making.

METHODS

Subjects

Twenty male and twenty female self-reported heterosexuals participated in the study. All participants were undergraduate or graduate students who gave informed consent. The study was approved by the Duke University Medical School Institutional Review Board and was performed in isolated testing cubicles on PC computers using Matlab and Psychtoolbox (Brainard, 1997).

Image Databases

Two databases were generated containing over 2,000 male and 2,000 female images. All images were downloaded from the Hotornot website (http://www.hotornot.com) in July 2006. This publicly accessible website allows anyone to post a photo and receive average attractiveness ratings from the browsing public. We selected images that had only a single central subject with a clearly visible face. We eliminated blurry photos, small photos, photos with animals or displays of wealth, photos in which emotionally salient objects such as guns, snakes, and motorcycles were visible, photos with subjects in provocative sexual positions or with nudity, and photos in which the subjects appeared to be younger than 18 years of age.

We ignored the website's posted ratings and reassessed attractiveness in a laboratory environment. Eleven males each rated all female photographs and eleven females each rated all male photographs. Raters were not used as test participants in the subsequent experiment. Ratings were made on a PC using a program that displayed each photo for one second and then waited for a rating. Raters could press a button to view each photograph again. The instructions asked raters to rate each image for attractiveness on a scale from one to ten, with ten being the most attractive.

All raw ratings were then standardized to z-scores, which revealed how many standard deviation units the given photograph was above or below the mean rating of the rater. These z-scores were then averaged to calculate a single composite rating for each photograph. Images with a high degree of inter-rater variance were discarded. Composite ratings were used to divide each database into three categories. The high attractiveness category consisted of the 100 most highly rated images in each database (mean raw score: males, 7.4; females, 6.89); the neutral category consisted of 200 images around the average of the distribution (mean raw score: males, 5.44; females, 4.47); the low attractiveness category consisted of the 100 lowest rated images (mean rating: males, 2.92; females, 2.38). In all tasks, male participants viewed only photos of females and vice versa.

Intertemporal choice task

Participants were seated at a computer in a private room and were read instructions from a script (see Figure 1 for a schematic of the task). Two options appeared on each trial. Below each option was displayed information about the delay, duration and attractiveness (number of stars) associated with an image presentation. One option (immediate) offered an immediate 1-second presentation; the other option (delayed) offered a presentation that was delayed (0.5 – 30 sec.) and of variable duration (1 – 8 sec.). However, both options offered identical attractiveness levels on any given trial. For the delayed option, the value for the delay and the duration of image presentation changed randomly from trial to trial. In addition, the relative onscreen position of the immediate or delayed options varied randomly on each trial. Selection of either option was followed by presentation of an image drawn from the indicated attractiveness category at the indicated time delay and presentation duration. Each presentation was followed by a subsequent delay such that the trial length was identical whether the immediate or delayed option was chosen. This eliminated the possible confounding variable of a participant actively attempting to decrease the amount of time spent performing the experiment.

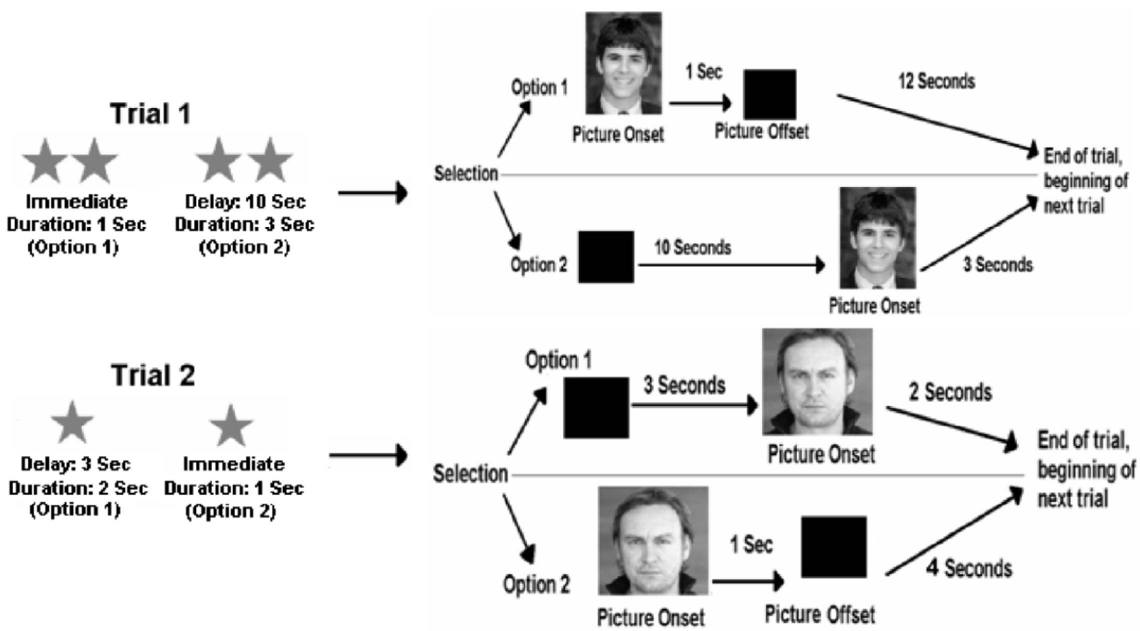


FIGURE 1. The intertemporal choice task. The figure indicates two separate trials performed in sequence (1 and 2). On each trial, subjects were given a choice between seeing an image for 1 second immediately or seeing the same image for a longer duration (randomly assigned between 1-8 sec) in the future (delayed option; delay randomly selected between 0.5-30 sec). The delay following the image was modified so that the total time for image presentation rate remained constant within the trial. On any given trial, Option 1 was equally likely to be the immediate or the delayed choice. The number of stars ranged from 1-3 and three stars indicated the most attractive category.

DATA ANALYSIS

Hyperbolic discount parameters were determined for each trial and for each subject, as described previously (Mazur, 1987). The discount parameter was calculated using the formula k=(v/v′ – 1)/D, where v′ equals the value of the immediately available reward (always one second), v is the value of the delayed reward (in seconds), k is the discount parameter, and D is the amount of time until receipt of the delayed reward. After each individual trial, a data file that recorded the parameter value of the given trial and the decision made by the participant (to receive either the immediate or delayed reward) was updated automatically. A graph depicting the relationship between option choice and discount parameter was then constructed from these data (see Figure 2 for an example). A Matlab script determined the linear best fit relationship for these parameters and the point at which this line intersected the midpoint between "immediate" and "delayed" options determined the subject's point of indifference across all 100 trials. This point was defined as the degree to which the subject discounted photos throughout the experiment.

Trial	Delay (D)	Delayed Picture Duration (v)	Option Chosen	Discount Parameter (k)
1	10 secs.	3 sec.	Delayed	0.20
2	30 secs.	3 sec.	Immediate	0.13
3	1 sec.	1.1 sec.	Immediate	0.10
4	3 secs.	3 sec.	Delayed	0.66

*NOTE: Immediate option corresponded to a delay of 0 sec and duration of 1 sec (v′).

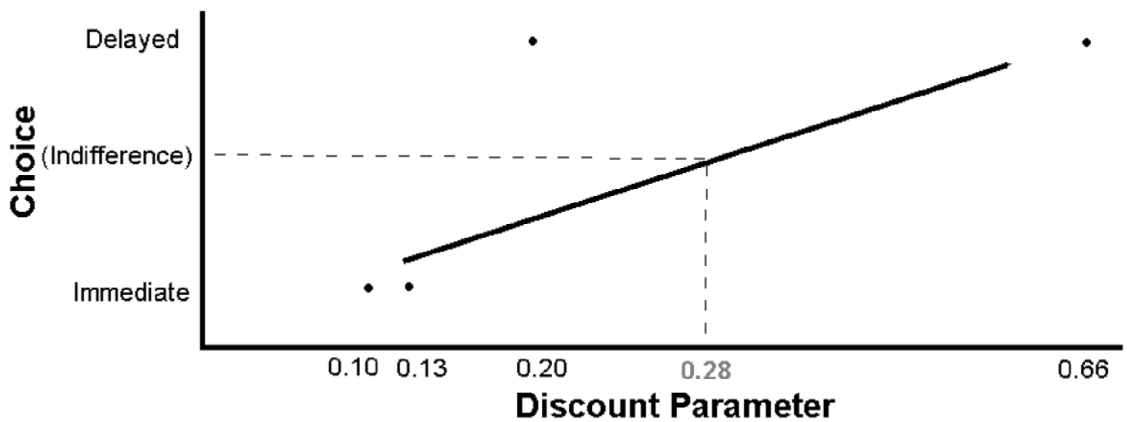


FIGURE 2. Estimation of overall level of indifference (discount parameter k). The relationship between option choice and the discount parameter over all trials was used to plot a line from which an overall discount parameter was determined. This parameter was defined as the point of intersection of the line with the midpoints between the two values for choice (y axis) and discount parameter (x axis). Data used to construct this graph are displayed in the associated table. Through the first four trials the participant had an average discount parameter of 0.28.

After determining the discount parameter value k (point of indifference) for all trials, the relative value of each photo was determined when the immediate option was chosen by solving for v (the value of the delayed reward) in the equation v′=v/(1+kD) (see Figure 3 for an example of this task using trial 2 from Figure 2). The value of v calculated in this way differed from the v value calculated using the discount parameter k from the individual trial. The difference between these two values represented the amount by which the image was discounted over time, i.e. the calculated value for v, which differed from the value present in the trial, represented the minimum duration for which the picture had to be presented in order for that subject to choose the delayed rather than the immediate option.

Trial 2

$$v' = \frac{v}{1 + kD} \longrightarrow v = v'(1+kD) \longrightarrow v = 1(1+0.28(30)) = 9.4 \text{ secs.}$$

FIGURE 3. Determination of the relative value of the image in Trial 2 from Figure 2. In this trial, based on the participant's parameter value across all trials (0.28), the option for picture duration in Trial 2 must have been at least 9.4 seconds in order for the participant to choose the delayed option. However, the duration given was only 3 seconds; therefore, the immediate option was chosen.

Statistical Analyses

Student's t-tests were used to compare mens' average rating of images of women and womens' average rating of images of men. In addition, student's t-tests were used to compare the average discount parameter across all attractiveness categories for both men and women. A bootstrap test was used to evaluate the tendency of all participants to discount the opportunity to view images of the opposite sex as delay increased and viewing duration decreased. A bootstrap test was used in order to estimate a distribution by sampling with replacement from the original sample. The level of significance for these tests was set at $\alpha=0.05$.

RESULTS

Eleven volunteers each rated ~2000 photographs of members of the opposite sex on a 1 to 10 scale (see Methods). Overall, there was a wide range of variation of physical attractiveness ratings for both men and women (Figure 4). The average rating for images of women by men (5.23) was significantly greater ($p<0.0001$) than the average rating for images of men by women (4.48). Moreover, men more closely agreed on assessments of female physical attractiveness than did women assessing male attractiveness. The average inter-subject correlation for men rating pictures of women (0.51) was greater ($p<0.01$) than the inter-subject correlation for women rating pictures of men (0.43).

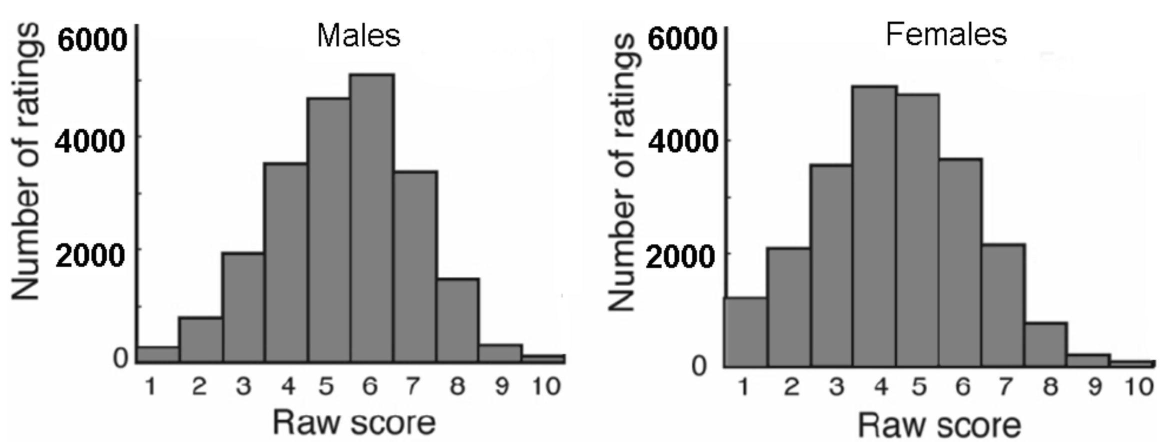


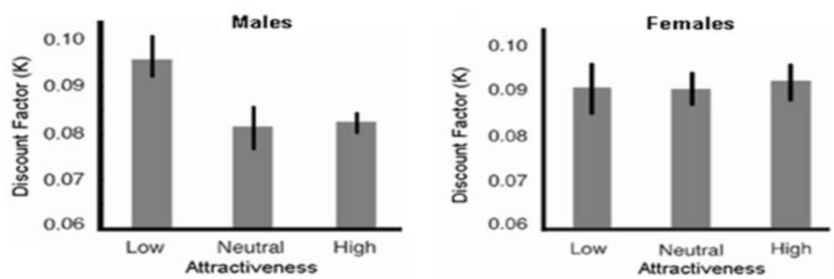
FIGURE 4. Physical attractiveness ratings. Histogram of ratings of all images in the database for male subjects rating female attractiveness and female subjects rating male attractiveness. Images were rated on a scale of 1 (least attractive) to 10 (most attractive).

We next asked participants (20 males and 20 females) to choose between immediate but brief, or delayed but longer, presentations of photographs of members of the opposite sex (Figure 1). We assumed that if social images function as rewards for humans, then increased viewing time is equivalent to receiving a greater reward and thus should be preferred. This assumption was supported by control trials in which the two options offered an identical delay until image onset but differed in the duration of image presentation. During control trials, participants consistently chose the option which allowed a longer viewing duration. Results from the control trials therefore demonstrated that participants were not randomly selecting options from trial to trial. When we computed the tradeoff between delay and viewing duration for each subject, we found that as the delay time increased, the subjects increasingly favored the immediate option. Across all participants, 36/40 (90%) showed a greater tendency to discount the opportunity to view images of the opposite sex as delay increased and viewing duration decreased ($p<0.05$, bootstrap test for significance).

A comparison of discount factors between males and females for each category revealed striking sex-based differences (Figure 5a). Although the average discount factor for males ($k=0.084$) and females (0.085) was virtually identical when combined across all attractiveness classes ($p=0.85$), male participants discounted the opportunity to view unattractive females more steeply than neutral or attractive females ($p<0.001$), whereas the female discount factor was not influenced by the attractiveness of the image ($p>0.05$). When an attractive picture was about to be seen, only male participants were more likely to choose the delayed option with a longer duration.

Finally, when determining the relative value of an image based on the given delay and duration presented in the trial, it was observed that the image value decreased most steeply during the initial stages of delay. For example, if the delay in two separate trials was 5 seconds and 10 seconds (a difference of 5 seconds), the relative value of an image may have decreased by 40%. However, if the delay in two separate trials was 20 seconds and 25 seconds (also a difference of 5 seconds), the relative value of the image decreased less dramatically, perhaps by only 10%. These findings for both males and females can be seen in Figure 5b.

a.



b.

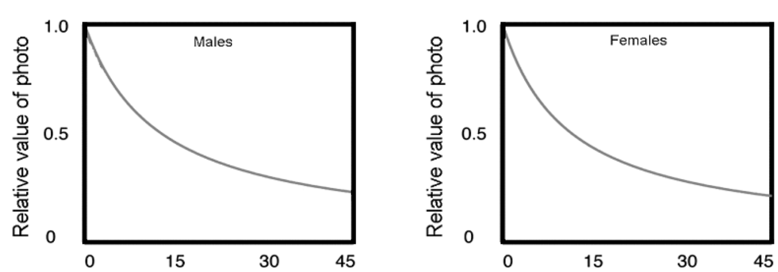


FIGURE 5.
a) Comparison of discount factors between males and females over a range of image attractiveness. The discount factors of males were sensitive to the attractiveness of the photos while the discount factors of females were independent of the attractiveness of the photos.
b) The relative value of an image decreases as the time delay until viewing the image increases. During initial stages of delay, the relative value of an image decreased dramatically for both males and females. However, as this delay increased, the relative value did not decline as steeply.

DISCUSSION

Social orienting decisions require selection of certain stimuli for viewing others (Platt, 2002). This decision process is presumably mediated by the expected value of visual information (Deaner et al., 2005). Nonetheless, the processes that transform the expected value of social information into visual orienting behavior remain poorly understood. Our results indicate that standard neuroeconomic principles may apply to social orienting decisions, just as they apply to decisions about appetitive and monetary rewards (Winston et al., 2007 and Mazur, 1987). Using this comparative framework, we made several important new observations.

First, classical economic theory predicts that delay should not affect choice (Mazur, 1987). In the present study, therefore, the delayed option should always have been preferred since it presented the image (reward) for a longer period of time. However, our finding that the immediate option was chosen in many instances is inconsistent with the classic economic assumption that humans and animals make rational decisions (Mazur, 1987). Second, physical attractiveness influences discounting of social images in males. Specifically, males discount less for physically attractive females than for physically unattractive females. Finally, the relative value of an image decays most dramatically during the initial stages of delay. These findings closely parallel previous studies examining the valuation of monetary and appetitive rewards. For instance, Mazur (Mazur, 1987) and Giordano (Giordano et al., 2002) provided evidence that food, drugs, and money are all discounted most steeply during initial delay and the degree to which they are discounted increases with the amount of the given reward. Our finding that social information parallels these previous studies suggests that attractiveness is a valued commodity and that it is one dimension that can contribute to determining the value of rewards.

Although striking similarities were found between the assessment of social information and food or money, our finding that males exhibited greater sensitivity to physical attractiveness than did females was striking. The wide discrepancy in valuation of images by the two sexes distinguishes social images from goods such as money and food, which are thought to have approximately similar value functions for men and women. These results suggest that male valuation of female images is strongly influenced by physical attractiveness, whereas female valuation of male images is not. These results are consistent with other studies reporting a greater importance of physical attractiveness for men (Aharon et al., 2001). By contrast, we know of no studies showing sex differences in discounting of monetary rewards.

The neural systems underlying valuation in general, and intertemporal choice in particular, remain a subject of intense scrutiny (Deldin et al., 2000). Recent studies have implicated a widespread brain network that includes the orbitofrontal cortex (Schultz, 2006), the parietal cortex, the ventral striatum, and medial frontal cortex in value-based decisions (Platt, 2002). It has been argued that a more medial and a more lateral system serve complementary roles in evaluating rewards at near and distant times, respectively (McClure et al., 2004). Our finding that temporal discounting applies to non-monetary rewards suggests that these areas may mediate all types of valuation decisions, including visual orienting. These two systems appear to be subsets of a larger set of circuits that mediate decision-making about social information. For example, it is likely that orienting in the presence of threatening visual social information is mediated by distinct neural circuitry including the amygdala and insula (Anderson et al., 2003).

Further to assess whether a shared neural system mediates both social and non-social decision-making, it will be necessary to examine other types of social behaviors, using both animal models and human studies. For example, training rhesus macaque monkeys to perform intertemporal tasks to determine whether they discount the opportunity to view photos of other monkeys at various levels of their own social hierarchy could complement human studies and may allow localization of activated brain areas via neurophysiologic recording techniques. In addition, human participants performing the same intertemporal task during fMRI imaging should provide direct evidence of the brain areas associated with the valuation of attractiveness. A comparison of brain structures activated during social orienting with those activated during tasks associated with monetary or appetitive rewards could provide insight into the commonality of brain systems that mediate these functions.

In summary, our findings imply that a shared valuation system mediates decisions about social information and decisions about both primary (food) and abstract (monetary) commodities. This system may be disrupted in certain neurological disorders such as autism (Klin et al., 2002), schizophrenia (Langdon et al., 2006), and depression (Deldin et al., 2000) that are characterized by both social and nonsocial deficits in behavioral valuation. For example, social orienting deficits in autism may result, in part, from a failure to assign motivational valence to faces. This hypothesis has led to novel treatments for autism using operant conditioning of social stimuli (Baron-Cohen and Belmont, 2005). A failure to assign proper valence to social stimuli may also underlie the Capgras Syndrome, which is characterized by the feeling that familiar people are actually imposters (Ellis and Young, 1990). Such breakdowns in assigning motivational value to social information in neurological disorders highlight the clinical importance of fully elucidating the neural mechanisms underlying socially-motivated orienting.

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