Marketing actions can modulate neural representations of experienced pleasantness

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Supporting Information

Files in this Data Supplement:

SI Figure 5

Fig. 5. Activation maps for the contrast high-low price for wines 1 and 2. This figure shows the same contrast as Fig. 2 *B* and *C* and *E* and *F*, but at a much lower threshold.

Table 1. List of wines used in the study

Wine	Quality rating	Price	Vintage	Appellation	Grape
1	80	$5-$6	Mixed vintage	Mixed Napa Valley/Central Coast	Cabernet Sauvignon
2	91	$90	2002	Napa Valley	Cabernet Sauvignon
3	92	$35	2002	Napa Valley	Cabernet Sauvignon

Table 2. Results for the contrast wine 1 at high vs. low price (upper) during sampling, and (lower) at swallowing

MNI-coordinate (*x*, *y*, *z*)	Region	Side	BA	T
-12, -90, -6	Lingual gyrus	L	17	5.77
30, 30, 24	Middle frontal gyrus, DLPFC	R	9	5.17
-6, 0, 39	Cingulate gyrus	L		4.55
-12, 36, -9	Medial frontal gyrus, mOFC/VMPFC	L	10/11	4.87
15, -93, -3	Lingual gyrus	R	17	4.03
-42, -24, -6	Middle temporal gyrus	L	47	5.17
-18, 42, 6	Middle frontal gyrus/VMPFC/ACC	L	10	3.94
-24, 30, -4	Inferior frontal gyrus,	L	47	3.81

Height threshold: T = 3.61, $P = 0.001$(unc.). Extent threshold: $k = 5$ voxels.

MNI-coordinate (x, y, z)	Region	Side	BA	T
-4, -10, -9	Brainstem, midbrain	L		3.85*
9, -60, -42	Cerebellum, posterior lobe	R		3.74
9, -60, 15	Posterior cingulate cortex	R	30	3.54
4, 27, -4	Anterior cingulate cortex	R	24	3.26
21, 42, 54	Superior frontal gyrus	R	8	3.25
-2, 27, -2	Anterior cingulate cortex	L	24/32	3.24
3, -40, -33	Brainstem, pons	R		3.20
3, -27, -12	Brainstem, midbrain	R		3.19
9, -42, -1	Parahippocampal gyrus	R	30	3.11
-6, -49, 16	Posterior cingulate cortex	L	30	2.9

Height threshold: T = 2.806, P = 0.005(unc.). Extent threshold: k = 5 voxels

*Also survives P = 0.001(unc.) and T = 3.5794.

Table 3. Results for the contrast wine 1 at low vs. high price (upper) during sampling and (lower) at swallowing

MNI-coordinate (x, y, z)	Region	Side	BA	T
57, 18, 3	Inferior frontal gyrus	R	45	3.94*
57, 12, 24	Inferior frontal gyrus	R	45	3.81
54, 12, 45	Middle frontal gyrus, DLPFC	R	8	3.11

Height threshold: T = 2.8609, P = 0.005(unc.). Extent threshold: k = 5 voxels

*Also survives P = 0.001(unc.) and T = 3.5794.

MNI-coordinate (x, y, z)	Region	Side	BA	T
57, 16, 3	Inferior frontal gyrus	R	45	3.73*
-43, 50, 3	Inferior frontal gyrus	L	10	3.65*

Height threshold: T = 2.8609, P = 0.005(unc.). Extent threshold: k = 5 voxels.

*Also survives P = 0.001(unc.) and T = 3.5794.

Table 4. Results for the contrast wine 2 at high vs. low price (upper) during sampling and (lower) at swallowing

MNI-coordinate (*x*, *y*, *z*)	Region	Side	BA	T
63, -9, -21	Inferior temporal gyrus	R	21	6.13
-30, -24, -6	Precentral gyrus	L	4	5.64
-2, 48, -20	Medial frontal gyrus, mOFC	L	11	4.99
3, 48, -19	Medial frontal gyrus, mOFC	R	11	4.99
21, 0, -18	Amygdala	R		4.96
6, -57, 24	Posterior cingulate cortex	R	31	4.84
39, 27, -21	Middle frontal gyrus/lOFC	R	11/47	4.52
9, 39, -9	Medial frontal gyrus/ACC	R	10/32	4.51
57, 21, 33	Middle frontal gyrus, DLPFC	R	9	4.35
9, 54, -3	Medial frontal gyrus, VMPFC	R	10	4.34
-50, 2, -27	Middle temporal gyrus	L	21	4.15
15, 30, 57	Superior frontal gyrus	R	8	4.03

Height threshold: T = 3.5794, *P* = 0.001(unc.). Extent threshold: *k* = 5 voxels.

MNI-coordinate (*x*, *y*, *z*)	Region	Side	BA	T
-54, 3, -27	Middle temporal gyrus	L	21	5.38*
3, 33, -21	Medial rectal/frontal gyrus, mOFC	R	11	4.85*
9, 51, -6	Medial frontal gyrus, VMPFC	R	11	4.82*
3, -24, -21	Brainstem, midbrain	R		4.52*
33, -18, -21	Parahippocampal gyrus	R		3.16
9, -48, 12	Posterior cingulated	R		3.16

Height threshold: T = 2.806, *P* = 0.005(unc.). Extent threshold: *k* = 5 voxels.

*Also survives *P* = 0.001(unc.) and T = 3.5794.

Table 5. Results for the contrast wine 2 at low vs. high price (upper) during sampling and (lower) at swallowing

MNI-coordinate (*x*, *y*, *z*)	Region	Side	BA	T
-1, -45,-12	Cerebellum, culmen	L		4.08
-27, 31, 24	Frontal lobe, sub-gyral	L		3.41
24, 33, 30	Frontal lobe, sub-gyral	R		3.34
36, 42, 42	Middle frontal gyrus, DLPFC	R	9	3.35

Height threshold: T = 2.8609, *P* = 0.005(unc.). Extent threshold: *k* = 5 voxels.

MNI-coordinate (*x*, *y*, *z*)	Region	Side	BA	T
51, -27, 6	Superior temporal gyrus	R	22*	7.58
14, -22, 38	Cingulate gyrus	R	24*	5.67
18, 49, -9	Parahippocampal gyrus	R	19*	5.31
-48, 25, 0	Inferior frontal gyrus	L	47*	5.14
-51, -27, 0	Superior temporal gyrus	L	22*	4.92
52, 26, 0	Inferior frontal gyrus	R	47	3.91
-9, 3, 43	Cingulate gyrus	L	24	3.90
38, -23, 19	Posterior insula	R	13	3.54
-60, -39, -3	Middle temporal gyrus	L	21	3.45
33, -66, 0	Middle occipital gyrus/lingual gyrus	R	24	

Height threshold: T = 2.806, P = 0.005(unc.). Extent threshold: k = 5 voxels.

*Also survives P = 0.001(unc.) and T = 3.5794.

Table 6. Results for the conjunction analysis for wines 1 and 2 comparing activity at high vs. low price (upper) during sampling and (lower) at swallowing

A.

MNI-coordinate (*x*, *y*, *z*)	Region	Side	BA
-4, 43, -16	Medial frontal gyrus, mOFC/ACC	L	11/32
4, 33, -13	Medial frontal gyrus, mOFC	R	11

Height threshold: T = 2.87, P = 0.005(unc.). Extent threshold: k = 5 voxels.

MNI-coordinate (*x*, *y*, *z*)	Region	Side	BA
-6, -15, -12	Brainstem, midbrain	L	
5, 38, -9	Medial frontal gyrus, ACC	R	11/32
-3, 45, -18	Medial frontal gyrus, ACC	L	11/32
4, -39, -38	Brainstem, pons	R	
9, -51, 15	Posterior cingulate	R	

Height threshold: T = 2.87, P = 0.005(unc.). Extent threshold: k = 5 voxels.

Table 7. Results for the contrast administration of a wine vs. neutral solution (upper) during tasting (lower) at swallowing

MNI	Area	Side	BA	T
-33, -93, -3	Middle occipital gyrus	L	18	3.86

Height threshold: T = 3.5794, *P* = 0.001(unc.). Extent threshold: *k* = 5 voxels.

MNI	Area	Side	BA	T
-32, 24, 3	Anterior insula	L	13	5.51
32, 24, 3	Anterior insula	R	13	5.15
12, 24, 30	Anterior cingulate	R	24	4.90
5, 24, 48	Medial frontal gyrus	R	6/8	5.28
-3, 24, 47	Medial frontal gyrus	L	6/8	5.27
21, 45, 36	Superior frontal gyrus	R	9	4.50
-27,-51,-33	Cerebellum, anterior lobe, culmen	L		4.22
24, 45, 15	Subgyral	R		4.07
-6, 12, 6	Caudate	L		3.97
10, 15, 10	Caudate	R		3.98

Height threshold: T = 3.5794, *P* = 0.001(unc.). Extent threshold: *k* = 5 voxels.

Table 8. Results for the interaction analysis (upper) for [$45-$5] -[$90-$10] (lower) for [$90-$10]-[$45-$5]

MNI-coordinate (*x*, *y*, *z*)	Region	Side	BA	T
-18, -84, 0	Lingual gyrus	L	17	5.95
18, -84, -3	Lingual gyrus	R	17	5.14
33, 30, 21	Subgyral	R		4.87
-27,-45, -33	Cerebellum, anterior lobe, culmen	L		4.82
-27, 54, 30	Superior frontal gyrus	L	10	4.06
-54, 3, -15	Inferior parietal lobule	L	22	3.91
-2, 18, -17	Medial frontal gyrus, mOFC	L	25/11	3.88
-18, 5, 57	Medial frontal gyrus	L	6	3.61

Height threshold: T = 3.5794, *P* = 0.001(unc.). Extent threshold: *k* = 5 voxels.

MNI	Area	Side	BA	T
48, 27, 9	Inferior frontal gyrus	R	45	3.74

Height threshold: T = 3.5794, *P* = 0.001(unc.). Extent threshold: *k* = 5 voxels.

Table 9. Areas in which activity during sampling is modulated by the liking ratings

MNI	Area	Side	BA	T
-3, 48, -18	mOFC/VMPFC	L	11	4.10
1, -39, -33	Brainstem	R		4.30

Height threshold: T = 3.58, *P* = 0.001(unc.). Extent threshold: *k* = 4 voxels.

SI Text

fMRI Data Analysis

Data analysis was done using two different models:

Model 1

The data analysis proceeded in three steps. In the first step, we estimated a general linear model with AR(1) and the following independent variables for each of the four sessions:

1 $I\$5 * I_{@sampling}$

2 $I\$10 * I_{@sampling}$

3 $I\$35 * I_{@sampling}$

4 $I\$45 * I_{@sampling}$

5 $I\$90 * I_{@sampling}$

6 $IN * I_{@sampling}$

7 $I\$5 * I_{@swallowing}$

8 $I\$10 * I_{@swallowing}$

9 $I\$35 * I_{@swallowing}$

10 $I\$45 * I_{@swallowing}$

11 $I\$90 * I_{@swallowing}$

12 $IN * I_{@swallowing}$

13 Five regressors of no interest

14 Seven motion regressors

15 Four session constants

These variables are defined as follows:

• $I_{\$x}$ equals 1 during a the trial of type *x* and equals 0 otherwise

• $I_{@sampling}$ equals 1 during the time the subjects had the liquids in their mouth (from delivery until the swallowing time detected by the neck coil). It equals 0 otherwise.

• $I_{@swallow}$ equals 1 during the first instant when the subject swallowed as detected by the swallowing coil and is 0 otherwise. This was modeled as stick function. The swallowing onsets were orthogonalized using SPM's orth function.

• The regressors of no interest included the following events: (1) entering a liking rating, (2) entering an intensity rating, (3) delivery of the neutral solution at the time of rinsing, (4) swallowing of the rinse solution, and (5) any uninstructed swallowing.

• The motion regressors include the six motion parameters produced during realignment (reflecting movements for each scan with respect to the first scan) and the output of the motion-detector coil, band-pass filtered appropriately (resampled from 400 to 25 samples/sec, high pass filtered with cutoff frequency of 0.2 Hz), and subsampled to the number of scans in the experiment.

Each of these regressors was convolved with a canonical hemodynamic response function (HRF).

Second, we calculated the following first-level single-subject contrasts:

1.1) Sampling period for wine 1 @ high minus low price (regressors 4 vs. 1)

1.2) Sampling period for wine 1 @ low minus high price (regressors 1 vs. 4)

1.3) Sampling period for wine 2 @ high minus low price (regressors 5 vs. 2)

1.4) Sampling period for wine 2 @ low minus high price (regressors 2 vs. 5)

1.5) Swallowing period for wine 1 @ high minus low price (regressors 10 vs. 7)

1.6) Swallowing period for wine 1 @ low minus high price (regressors 7 vs. 10)

1.7) Swallowing period for wine 2 @ high minus low price (regressors 11 vs. 8)

1.8) Swallowing period for wine 2 @ low minus high price (regressors 8 vs. 11)

1.9) Sampling period for all wines minus neutral (regressors 1-5 vs. 6)

1.10) Swallowing period for all wines minus neutral (regressors 7-11 vs. 12)

Finally, for each of these first level contrasts we calculated a second-level group contrast using a one sample *t* test.

We also performed an interaction analysis by calculating the following contrasts for each subject:

1.11) Sampling period for wine 1 @ high minus low price minus sampling period for wine 2 @ high minus low price (contrast: [$90-$10]-[$45-$5])

1.12) Sampling period for wine 2 @ high minus low price minus sampling period for wine 1 @ high minus low price (contrast: [$45-$5]-[$90-$10])

For each of these first level contrasts we calculated a second-level group contrast using a one sample *t* test.

The figures in the paper and supplementary materials are constructed using these second-level contrasts using a threshold of $P < 0.001$ uncorrected and a extend threshold of five contiguous voxels (unless otherwise indicated).

Model 2

The data analysis for this model also proceeded in three steps. In the first step, we estimated a general linear models with AR(1) and the following independent variables for each of the four sessions:

1 $I_{@sampling}$

2 $I_{@sampling}$ * liking rating

3 $I_{@sampling}$ * intensity rating

4 $I_{@swallowing}$

5 $I_{@swallowing}$* liking rating

6 $I_{@swallowing}$ * intensity rating

7 Five regressors of no interest

8 Seven motion regressors

9 Four session constants

These variables are defined as follows: -$I_{@sampling}$ equals 1 during the time the subjects had the liquids in their mouth (from delivery until the swallowing time detected by the swallowing coil). It equals 0 otherwise. -$I_{@swallow}$ equals 1 during the first instant when the subject swallowed as detected by the swallowing coil and is 0 otherwise. This was modeled as stick function. The swallowing onsets were orthogonalized using SPM's orth function. -'Liking rating' equals the linearly interpolated liking ratings entered by the subject for each liquid. -'Intensity rating' equals the linearly interpolated intensity ratings placed by the subject for each liquid. -The regressors of no interest included the following events: (1) entering a liking rating, (2) entering an intensity rating, (3) delivery of the neutral solution at the time of rinsing, (4) swallowing of the rinse solution, and (5) any uninstructed swallowing. -The motion regressors include the six motion parameters produced during realignment (reflecting movements for each scan with respect to the first scan) and the output of the motion-detector coil, band-pass filtered appropriately (resampled from 400 to 25 samples/sec, high pass filtered with cutoff frequency of 0.2 Hz), and subsampled to the number of scans in the experiment.

Each of these regressors was convolved with a canonical hemodynamic response function (HRF).

Second, we calculated the following first-level single-subject contrasts:

2.1) Modulation of liquid sampling period by liking rating (regressor 2) 2.2) Modulation of liquid sampling period by intensity rating (regressor 3) 2.3) Modulation of liquid swallowing period by liking rating (regressor 5) 2.4) Modulation of liquid swallowing period by intensity rating (regressor 6)

Finally, for each of these first level contrasts we calculated a second-level group contrast using a one sample *t* test.

Anatomical localizations were carried out by overlaying the t-maps on a normalized structural image averaged across subjects, and with reference to an anatomical atlas (1)

fMRI Results

Contrast 1.1: Sampling period for wine 1 @high vs. low price

Using a whole-brain analysis, we identified areas that showed increased activation during sampling of the first wine when it was identified by a high price vs. when it was identified by a low price. SI Table 2. A lists the results of this contrast and Fig. 2 *B* and *C* provide images of the areas of interest.

Contrast 1.2: Sampling period of wine 1 @ low vs. high price

Using a whole-brain analysis, we identified areas that showed increased activation during sampling of the first wine when it was identified by a low price vs. when it was identified by a high price. SI Table 3. A lists the results of this contrast for a threshold of $P < 0.005$ uncorrected and an extent threshold of five contiguous voxels.

Contrast 1.3: Sampling period of wine 2 @ high vs. low price

Using a whole-brain analysis, we identified areas that showed increased activation during sampling of the second wine when it was identified by a high price vs. when it was identified by a low price. SI Table 4. A lists the results of this contrast and Fig. 2 *E* and *F* provide images of the areas of interest.

Contrast 1.4: Sampling period of wine 2 @ low vs. high price

Using a whole-brain analysis, we identified areas that showed increased activation during sampling of the second wine when it was identified by a low price vs. when it was identified by a high price. SI Table 5. A lists the results of this contrast for a threshold of $P < 0.005$ uncorrected and an extent threshold of five contiguous voxels.

Contrast 1.5: Swallowing of wine 1 @ high vs. low price

Using a whole-brain analysis, we identified areas that showed increased activation at the time of swallowing the first wine when it was identified by a high price vs. when it was identified by a low price. SI Table 2*B* lists the results of this contrast when using a threshold of $P < 0.005$ uncorrected and an extent threshold of five contiguous voxels.

Contrast 1.6: Swallowing of wine 1 @ low vs. high price

Using a whole-brain analysis, we identified areas that showed increased activation at the time of swallowing the first wine when it was identified by a low price vs. when it was identified by a high price. SI Table 3*B* lists the results of this contrast when using a threshold of $P < 0.005$ uncorrected and an extent threshold of five contiguous voxels.

Contrast 1.7: Swallowing of wine 2 @ high vs. low price

Using a whole-brain analysis, we identified areas that showed increased activation at the time of swallowing the second wine when it was identified by a high price vs. when it was identified by a low price. SI Table 4*B* lists the results of this contrast when using a threshold of $P < 0.005$ uncorrected and an extent threshold of five contiguous voxels.

Contrast 1.8: Swallowing of wine 2 @ low vs. high price

Using a whole-brain analysis, we identified areas that showed increased activation at the time of swallowing the second wine when it was identified by a low price vs. when it was identified by a high price. SI Table 5*B* lists the results of this contrast when using a threshold of $P < 0.005$ uncorrected and an extent threshold of five contiguous voxels.

Conjunction Analysis: Both wines during sampling @ high vs. low price

We performed a conjunction analysis using an inclusive mask (based on the contrast high-low price for wine 1) to identify areas that showed significant changes in neural activation for both wines when identified by the high price vs. the low price during the sampling period. We did this in two steps. First, each individual contrast was thresholded at $P < 0.001$.

Second, we looked for areas showing overlapping significant effects in each of the individual contrasts. Note that this method requires each of the comparisons in the conjunction to be individually significant. SI Table 6*A* and Fig. 3 show the results of this contrast when using a threshold of $P < 0.005$ uncorrected and an extent threshold of five contiguous voxels.

Conjunction Analysis: Both wines administered at high vs. low price after swallowing

Accordingly, we performed a conjunction analysis using an inclusive masking procedure (based on the contrast high-low price for wine 1) to identify areas that showed significant changes in neural activation for both wines during swallowing. SI Table 6*B* shows the results of this contrast when using a threshold of $P < 0.005$ uncorrected and an extent threshold of five contiguous voxels.

Contrast 1.9: Wine versus neutral solution during sampling

Using a whole-brain analysis, we identified areas that showed increased activation during the sampling period when a wine was administered as compared to the neutral solution. SI Table 7*A* lists the results of this contrast.

Contrast 1.10: Wine versus neutral solution during swallowing

Using a whole-brain analysis, we identified areas that showed increased activation at the time of swallowing when a wine was administered as compared to the neutral solution. SI Table 7*A* lists the results of this contrast.

Contrast 1.11: Interaction analysis low quality wine @high minus low price minus high quality wine @high minus low price

Using a whole-brain analysis, we identified areas that showed increased activation during sampling of the low-quality wine when it was identified by a high vs. a low price as compared to the high-quality wine when it was identified by a high vs. a low price. SI Table 8*A* lists the results of this contrast.

Contrast 1.12: Interaction analysis high quality wine @ high minus low price minus low quality wine @ high minus low price

Using a whole-brain analysis, we identified areas that showed increased activation during sampling of the high-quality wine when it was identified by a high vs. a low price as compared to the low-quality wine when it was identified by a high vs. a low price. SI Table 8*B* lists the results of this contrast.

Contrast 2.1: Modulation by liking ratings during the sampling period.

Using a whole-brain analysis, we identified areas whose activation during the sampling period was modulated by the interpolated liking ratings. SI Table 9 and Fig. 4 show the results of this contrast.

Contrast 2.2: Modulation by intensity ratings during the sampling period

Using a whole-brain analysis, we identified areas whose activation during sampling period was modulated by the interpolated intensity ratings. No areas exhibited significant activation at a threshold of $P < 0.005$ uncorrected and an extent threshold of size of five contiguous voxels.

Contrast 2.3: Modulation by liking ratings during the swallowing period

Using a whole-brain analysis, we identified areas whose activation during swallowing was modulated by the interpolated liking ratings. No areas exhibited significant activation at a threshold of $P < 0.005$ uncorrected and an extent threshold of size of five contiguous voxels.

Contrast 2.4: Modulation by intensity ratings during the swallowing period

Using a whole-brain analysis, we identified areas whose activation during swallowing was modulated by the interpolated intensity ratings. No areas exhibited significant activation at a threshold of $P < 0.005$ uncorrected and an extent threshold of size of five contiguous voxels.

1. Duvernoy HM (1999) *The Human Brain: Surface, Three-Dimensional Sectional Anatomy with MRI, Blood Supply* (Springer, Berlin).