IN THE UNITED STATES DISTRICT COURT
FOR THE EASTERN DISTRICT OF TEXAS
MARSHALL DIVISION

PERCEPTIVE AUTOMATA, LLC,	)	
	)	
Plaintiff,	)	
v.	)	Civil Action No. 2:25-cv-742-JRG
	)	
TESLA, INC.,	)	
	)	
Defendant.	)	
	)	

DEFENDANT'S NOTICE OF SUBPOENA TO APPLE, INC.

Pursuant to Rule 45 of the Federal Rules of Civil Procedure, Tesla, Inc. ("Tesla"), by and through its counsel, requests documents and a deposition from Apple, Inc. pursuant to the attached Subpoena. A true and correct copy of the Subpoena is attached as Attachment A.

Dated: December 9, 2025

Respectfully submitted,

By: */s/ Roger Fulghum*
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Counsel for Tesla, Inc.

CERTIFICATE OF SERVICE

I hereby certify that all counsel of record are being served this 9th day of December 2025, by e-mail at the addresses indicated below:

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/s/ *Roger Fulghum*
Roger Fulghum

UNITED STATES DISTRICT COURT

for the

Eastern District of Texas

PERCEPTIVE AUTOMATA LLC *Plaintiff* v. TESLA, INC. *Defendant*	))))))	Civil Action No. 2:25-cv-00742-JRG

SUBPOENA TO TESTIFY AT A DEPOSITION IN A CIVIL ACTION

To: Apple Inc., One Apple Park Way, Cupertino, CA 95014

(Name of person to whom this subpoena is directed)

☑ Testimony: YOU ARE COMMANDED to appear at the time, date, and place set forth below to testify at a deposition to be taken in this civil action. If you are an organization, you must promptly confer in good faith with the party serving this subpoena about the following matters, or those set forth in an attachment, and you must designate one or more officers, directors, or managing agents, or designate other persons who consent to testify on your behalf about these matters:

Place:	Date and Time:
Baker Botts L.L.P., 1001 Page Mill Road, Building One, Suite 200, Palo Alto, CA 94304-1007	01/15/2026 9:00 am

The deposition will be recorded by this method: Stenographic and videotaped

☑ *Production:* You, or your representatives, must also bring with you to the deposition the following documents, electronically stored information, or objects, and must permit inspection, copying, testing, or sampling of the material:

See Attachment A

The following provisions of Fed. R. Civ. P. 45 are attached – Rule 45(c), relating to the place of compliance; Rule 45(d), relating to your protection as a person subject to a subpoena; and Rule 45(e) and (g), relating to your duty to respond to this subpoena and the potential consequences of not doing so.

Date: 12/09/2025

CLERK OF COURT

OR

	/s/ Roger Fulghum
Signature of Clerk or Deputy Clerk	*Attorney's signature*

The name, address, e-mail address, and telephone number of the attorney representing *(name of party)* Defendant, Tesla, Inc., who issues or requests this subpoena, are:

Roger Fulghum, Baker Botts L.L.P., 910 Louisiana, Houston, TX 77002; 713-229-1707; roger.fulghum@bakerbotts.com

Notice to the person who issues or requests this subpoena

If this subpoena commands the production of documents, electronically stored information, or tangible things before trial, a notice and a copy of the subpoena must be served on each party in this case before it is served on the person to whom it is directed. Fed. R. Civ. P. 45(a)(4).

Civil Action No. 2:25-cv-00742-JRG

PROOF OF SERVICE

(This section should not be filed with the court unless required by Fed. R. Civ. P. 45.)

I received this subpoena for *(name of individual and title, if any)* _____ on *(date)* _____ .

❒ I served the subpoena by delivering a copy to the named individual as follows: _____ on *(date)* _____ ; or

❒ I returned the subpoena unexecuted because: _____ .

Unless the subpoena was issued on behalf of the United States, or one of its officers or agents, I have also tendered to the witness the fees for one day's attendance, and the mileage allowed by law, in the amount of $ _____ .

My fees are $ _____ for travel and $ _____ for services, for a total of $ 0.00 .

I declare under penalty of perjury that this information is true.

Date: _____

_____
Server's signature

_____
Printed name and title

_____
Server's address

Additional information regarding attempted service, etc.:

Federal Rule of Civil Procedure 45 (c), (d), (e), and (g) (Effective 12/1/13)

(c) Place of Compliance.

(1) ***For a Trial, Hearing, or Deposition.*** A subpoena may command a person to attend a trial, hearing, or deposition only as follows:
(A) within 100 miles of where the person resides, is employed, or regularly transacts business in person; or
(B) within the state where the person resides, is employed, or regularly transacts business in person, if the person
(i) is a party or a party's officer; or
(ii) is commanded to attend a trial and would not incur substantial expense.

(2) ***For Other Discovery.*** A subpoena may command:
(A) production of documents, electronically stored information, or tangible things at a place within 100 miles of where the person resides, is employed, or regularly transacts business in person; and
(B) inspection of premises at the premises to be inspected.

(d) Protecting a Person Subject to a Subpoena; Enforcement.

(1) ***Avoiding Undue Burden or Expense; Sanctions.*** A party or attorney responsible for issuing and serving a subpoena must take reasonable steps to avoid imposing undue burden or expense on a person subject to the subpoena. The court for the district where compliance is required must enforce this duty and impose an appropriate sanction—which may include lost earnings and reasonable attorney's fees—on a party or attorney who fails to comply.

(2) ***Command to Produce Materials or Permit Inspection.***
(A) *Appearance Not Required.* A person commanded to produce documents, electronically stored information, or tangible things, or to permit the inspection of premises, need not appear in person at the place of production or inspection unless also commanded to appear for a deposition, hearing, or trial.
(B) *Objections.* A person commanded to produce documents or tangible things or to permit inspection may serve on the party or attorney designated in the subpoena a written objection to inspecting, copying, testing, or sampling any or all of the materials or to inspecting the premises—or to producing electronically stored information in the form or forms requested. The objection must be served before the earlier of the time specified for compliance or 14 days after the subpoena is served. If an objection is made, the following rules apply:
(i) At any time, on notice to the commanded person, the serving party may move the court for the district where compliance is required for an order compelling production or inspection.
(ii) These acts may be required only as directed in the order, and the order must protect a person who is neither a party nor a party's officer from significant expense resulting from compliance.

(3) ***Quashing or Modifying a Subpoena.***

(A) *When Required.* On timely motion, the court for the district where compliance is required must quash or modify a subpoena that:

(i) fails to allow a reasonable time to comply;
(ii) requires a person to comply beyond the geographical limits specified in Rule 45(c);
(iii) requires disclosure of privileged or other protected matter, if no exception or waiver applies; or
(iv) subjects a person to undue burden.
(B) *When Permitted.* To protect a person subject to or affected by a subpoena, the court for the district where compliance is required may, on motion, quash or modify the subpoena if it requires:
(i) disclosing a trade secret or other confidential research, development, or commercial information; or
(ii) disclosing an unretained expert's opinion or information that does not describe specific occurrences in dispute and results from the expert's study that was not requested by a party.
(C) *Specifying Conditions as an Alternative.* In the circumstances described in Rule 45(d)(3)(B), the court may, instead of quashing or modifying a subpoena, order appearance or production under specified conditions if the serving party:
(i) shows a substantial need for the testimony or material that cannot be otherwise met without undue hardship; and
(ii) ensures that the subpoenaed person will be reasonably compensated.

(e) Duties in Responding to a Subpoena.

(1) ***Producing Documents or Electronically Stored Information.*** These procedures apply to producing documents or electronically stored information:
(A) *Documents.* A person responding to a subpoena to produce documents must produce them as they are kept in the ordinary course of business or must organize and label them to correspond to the categories in the demand.
(B) *Form for Producing Electronically Stored Information Not Specified.* If a subpoena does not specify a form for producing electronically stored information, the person responding must produce it in a form or forms in which it is ordinarily maintained or in a reasonably usable form or forms.
(C) *Electronically Stored Information Produced in Only One Form.* The person responding need not produce the same electronically stored information in more than one form.
(D) *Inaccessible Electronically Stored Information.* The person responding need not provide discovery of electronically stored information from sources that the person identifies as not reasonably accessible because of undue burden or cost. On motion to compel discovery or for a protective order, the person responding must show that the information is not reasonably accessible because of undue burden or cost. If that showing is made, the court may nonetheless order discovery from such sources if the requesting party shows good cause, considering the limitations of Rule 26(b)(2)(C). The court may specify conditions for the discovery.

(2) ***Claiming Privilege or Protection.***
(A) *Information Withheld.* A person withholding subpoenaed information under a claim that it is privileged or subject to protection as trial-preparation material must:
(i) expressly make the claim; and
(ii) describe the nature of the withheld documents, communications, or tangible things in a manner that, without revealing information itself privileged or protected, will enable the parties to assess the claim.
(B) *Information Produced.* If information produced in response to a subpoena is subject to a claim of privilege or of protection as trial-preparation material, the person making the claim may notify any party that received the information of the claim and the basis for it. After being notified, a party must promptly return, sequester, or destroy the specified information and any copies it has; must not use or disclose the information until the claim is resolved; must take reasonable steps to retrieve the information if the party disclosed it before being notified; and may promptly present the information under seal to the court for the district where compliance is required for a determination of the claim. The person who produced the information must preserve the information until the claim is resolved.

(g) Contempt.
The court for the district where compliance is required—and also, after a motion is transferred, the issuing court—may hold in contempt a person who, having been served, fails without adequate excuse to obey the subpoena or an order related to it.

For access to subpoena materials, see Fed. R. Civ. P. 45(a) Committee Note (2013).

Attachment A

ATTACHMENT A

Pursuant to Rule 45 of the Federal Rules of Civil Procedure, Tesla is seeking the production of the documents requested below for inspection and copying. The due date for production set in this subpoena is January 15, 2026. Tesla is also seeking deposition testimony from Apple on the documents and topics set out below. The time and date for the deposition is January 15, 2026 at 9:00 am. Tesla is willing to negotiate with Apple an alternative date and time for both the production of documents, and a deposition. Materials produced in this litigation will be governed by the Protective Order entered in this case, dated November 21, 2025. *See* Attachment B.

DEFINITIONS

1. The terms "You", "Your", and "Apple" mean Apple, Inc., and each of that entity's parents, subsidiaries, divisions, affiliates, predecessors, assigns, successors, and acquired assets or business units, and any of its present or former officers, directors, trustees, employees, agents, representatives, attorneys, patent agents, and all other persons acting on its behalf.

2. The term "Emotient" means Emotient, Inc. and each of that entity's parents, subsidiaries, divisions, affiliates, predecessors, assigns, successors, and acquired assets or business units, and any of its present or former officers, directors, trustees, employees, agents, representatives, attorneys, patent agents, and all other persons acting on its behalf.

3. The term "Expression Analysis Product" means any facial expression analysis model or product that was designed, developed, tested, operated, offered for sale, used in commerce, or otherwise used by Emotient and/or Apple, whether in the United States or another country, before February 6, 2019 including, but not limited to, the Emotient FACET facial expression analysis engine.

INSTRUCTIONS

1. Tesla is seeking documents and information related to prior art for certain patents that were originally issued to Perceptive Automata, Inc. and later assigned to the plaintiff in this lawsuit, Perceptive Automata, LLC. Tesla is willing to meet and confer and answer any questions concerning the material sought in this subpoena. Please reach out to Roger Fulghum (roger.fulghum@bakerbotts.com or mobile:281-217-5031) or Mark Speegle (mark.speegle@bakerbotts.com or mobile 254-749-9120) with any questions concerning this subpoena.

REQUESTS FOR PRODUCTION

1. Documents sufficient to identify all Expression Analysis Products that were in public use, publicly demonstrated, offered for sale, used in commerce, or otherwise available to the public before each of the following dates: February 6, 2019; January 30, 2019; and July 5, 2017.

2. For each Expression Analysis Product, documents sufficient to establish when such Expression Analysis Product was first in public use, publicly demonstrated, offered for sale, used in commerce, or otherwise available to the public.

3. Documents sufficient to show the operation of (including inputs and outputs to) all machine learning models, algorithms, routines, methods, functions, or structures in relation to or within each Expression Analysis Product.

4. Documents sufficient to show the operation of the Emotient FACET facial expression analysis engine. *See* Attachment C at 21.

5. Documents sufficient to show when the Emotient FACET expression analysis engine was first in public use, publicly demonstrated, offered for sale, used in commerce, or otherwise available to the public. *See* Attachment C.

6. Documents sufficient to show the implementations of Emotient FACET facial analysis engine with Expression Analysis Products.

7. Documents sufficient to show how Emotient collected, stored, labeled, and/or generated training data used to train machine learning models implemented in or executed by the Expression Analysis Products.

8. Documents sufficient to show how the Expression Analysis Products "return a probabilistic result" of expression classification. *See* Attachment C at 22.

9. Documents sufficient to show how the Expression Analysis Products generate "numeric scores" including a "degree of confidence" representing the output of facial expression analysis models. *See* Attachment C at 30-34.

10. Documents sufficient to show the "purely statistical" classification performed by the Expression Analysis Products. *See* Attachment C at 20-22.

11. Documents sufficient to identify all products or services related to U.S. Patent No. 9,008,416 including all such products or services implementing U.S. Patent No. 9,008,416, whether in whole or in part.

DEPOSITION TOPICS

1. For the documents produced in response, testimony concerning the authenticity of each document and whether each document (A) was made at or near the time by — or from information transmitted by — someone with knowledge; (B) was kept in the course of a regularly conducted activity of a business, organization, occupation, or calling, whether or not for profit; and (C) was made as a regular practice of that activity.

2. The identity of all Expression Analysis Products that were in public use, publicly demonstrated, offered for sale, used in commerce, or otherwise available to the public before each of the following dates: February 6, 2019; January 30, 2019; and July 5, 2017.

3. The operation of (including inputs and outputs to) all machine learning models, algorithms, routines, methods, functions, or structures in relation to or within each Expression Analysis Product.

4. Attachment C, including the contents and the circumstances around its authorship and publication.

5. The operation and implementation of the Emotient FACET facial analysis expression engine in relation to the Expression Analysis Products. *See* Attachment C at 21.

6. The collection, storage, labeling, and/or generating of training data used to train machine learning models executed by or implemented in Expression Analysis Products.

7. How the Expression Analysis Products "return a probabilistic result" of expression classification. *See* Attachment C at 22.

8. How the Expression Analysis Products generate "numeric scores" including a "degree of confidence" representing the output of facial expression analysis models. *See* Attachment C at 30-34.

9. The "purely statistical" classification performed by the Expression Analysis Products. *See* Attachment C at 20-22.

10. All products or services related to U.S. Patent No. 9,008,416, including all such products or services implementing U.S. Patent No. 9,008,416, whether in whole or in part.

Attachment B

IN THE UNITED STATES DISTRICT COURT
FOR THE EASTERN DISTRICT OF TEXAS
MARSHALL DIVISION

PERCEPTIVE AUTOMATA LLC,	§	
	§	
Plaintiff,	§	
	§	Case No. 2:25-cv-00742-JRG
v.	§	
	§	JURY TRIAL DEMANDED
TESLA, INC.	§	
	§	
Defendant.	§	

PROTECTIVE ORDER

WHEREAS, Plaintiff Perceptive Automata LLC and Defendant Tesla, Inc., hereafter referred to as "the Parties," believe that certain information that is or will be encompassed by discovery demands by the Parties involves the production or disclosure of trade secrets, confidential business information, or other proprietary information;

WHEREAS, the Parties seek a protective order limiting disclosure thereof in accordance with Federal Rule of Civil Procedure 26(c):

THEREFORE, it is hereby stipulated among the Parties and ORDERED that:

1. Each Party may designate as confidential for protection under this Order, in whole or in part, any document, information or material that constitutes or includes, in whole or in part, confidential or proprietary information or trade secrets of the Party or a Third Party to whom the Party reasonably believes it owes an obligation of confidentiality with respect to such document, information or material ("Protected Material"). Protected Material shall be designated by the Party producing it by affixing a legend or stamp on such document, information or material as follows: "CONFIDENTIAL." The word "CONFIDENTIAL" shall be placed clearly on each page of the Protected Material (except deposition and hearing

transcripts) for which such protection is sought. For deposition and hearing transcripts, the word "CONFIDENTIAL" shall be placed on the cover page of the transcript (if not already present on the cover page of the transcript when received from the court reporter) by each attorney receiving a copy of the transcript after that attorney receives notice of the designation of some or all of that transcript as "CONFIDENTIAL."

2. Any document produced under Patent Rules 2-2, 3-2, and/or 3-4 before issuance of this Order with the designation "Confidential" or "Confidential - Outside Attorneys' Eyes Only" shall receive the same treatment as if designated "RESTRICTED - ATTORNEYS' EYES ONLY" under this Order, unless and until such document is redesignated to have a different classification under this Order.

3. With respect to documents, information or material designated "CONFIDENTIAL, "RESTRICTED - ATTORNEYS' EYES ONLY," or "RESTRICTED CONFIDENTIAL - SOURCE CODE" ("DESIGNATED MATERIAL"),[1] subject to the provisions herein and unless otherwise stated, this Order governs, without limitation: (a) all documents, electronically stored information, and/or things as defined by the Federal Rules of Civil Procedure; (b) all pretrial, hearing or deposition testimony, or documents marked as exhibits or for identification in depositions and hearings; (c) pretrial pleadings, exhibits to pleadings and other court filings; (d) affidavits; and (e) stipulations. All copies, reproductions, extracts, digests and complete or partial summaries prepared from any DESIGNATED MATERIALS shall also be considered DESIGNATED MATERIAL and treated as such

[1] The term DESIGNATED MATERIAL is used throughout this Protective Order to refer to the class of materials designated as "CONFIDENTIAL," "RESTRICTED - ATTORNEYS' EYES ONLY," or "RESTRICTED CONFIDENTIAL - SOURCE CODE," both individually and collectively.

under this Order.

4. A designation of Protected Material (i.e., "CONFIDENTIAL," "RESTRICTED - ATTORNEYS' EYES ONLY," or "RESTRICTED CONFIDENTIAL SOURCE CODE") may be made at any time. Production of documents, information, or material that has not been designated as DESIGNATED MATERIAL, whether inadvertently or otherwise, shall not be deemed a waiver in whole or in part of a claim for confidential treatment. Any party that inadvertently or otherwise produces Protected Material without designating it as DESIGNATED MATERIAL may request destruction of that Protected Material by notifying the recipient(s), as soon as reasonably possible after the Producing Party becomes aware of the inadvertent or unintentional disclosure, and providing replacement Protected Material that is properly designated. The recipient(s) shall then destroy all copies of the inadvertently or unintentionally produced Protected Materials and any documents, information or material derived from or based thereon.

5. "CONFIDENTIAL" documents, information and material may be disclosed only to the following persons, except upon receipt of the prior written consent of the designating party, upon order of the Court, or as set forth in paragraph 12 herein:

(a) Outside Counsel of Record in this Action for the Parties;

(b) employees of such counsel assigned to and reasonably necessary to assist such counsel in the litigation of this Action;

(c) in-house counsel for the Parties who either have responsibility for making decisions dealing directly with the litigation, or who are assisting outside counsel in the litigation;

(d) up to and including three (3) designated representatives of each of the Parties to the extent reasonably necessary for the litigation of this Action, except that either party may in good faith request the other party's consent to designate one or more additional representatives, the other party shall not unreasonably withhold such consent, and the requesting party may seek leave of Court to designate such

additional representative(s) if the requesting party believes the other party has unreasonably withheld such consent;

(e) outside consultants or experts (*i.e.*, not existing employees or affiliates of a Party or an affiliate of a Party) retained for the purpose of this litigation, provided that: (1) such consultants or experts are not presently employed by the Parties hereto for purposes other than this Action; (2) before access is given, the consultant or expert has completed the Undertaking attached as Exhibit A hereto and the same is served upon the Producing Party with a current curriculum vitae of the consultant or expert, including a list of other cases from the prior five (5) years in which the individual has provided a report or testified (at trial or at deposition, at least ten (10) days before access to the Protected Material is to be given to that consultant or Undertaking to object to and notify the Receiving Party in writing that it objects to disclosure of Protected Material to the consultant or expert. The Parties agree to promptly confer and use good faith to resolve any such objection. If the Parties are unable to resolve any objection, the objecting Party may file a motion with the Court within fifteen (15) days of the notice, or within such other time as the Parties may agree, seeking a protective order with respect to the proposed disclosure. The objecting Party shall have the burden of proving the need for a protective order. No disclosure shall occur until all such objections are resolved by agreement or Court order;

(f) independent litigation support services, including persons working for or as court reporters, graphics or design services, jury or trial consulting services, and photocopy, document imaging, and database services retained by counsel and reasonably necessary to assist counsel with the litigation of this Action; and

(g) the Court and its personnel.

6. A Party shall designate documents, information or material as "CONFIDENTIAL" only upon a good faith belief that the documents, information or material contains confidential or proprietary information or trade secrets of the Party or a Third Party to whom the Party reasonably believes it owes an obligation of confidentiality with respect to such documents, information or material.

7. Documents, information or material produced pursuant to any discovery request in this Action, including but not limited to Protected Material designated as DESIGNATED MATERIAL, shall be used by the Parties only in the litigation of this Action and shall not be used for any other purpose. Any person or entity who obtains access to DESIGNATED

MATERIAL or the contents thereof pursuant to this Order shall not make any copies, duplicates, extracts, summaries or descriptions of such DESIGNATED MATERIAL or any portion thereof except as may be reasonably necessary in the litigation of this Action. Any such copies, duplicates, extracts, summaries or descriptions shall be classified DESIGNATED MATERIALS and subject to all of the terms and conditions of this Order.

8. To the extent a Producing Party believes that certain Protected Material qualifying to be designated CONFIDENTIAL is so sensitive that its dissemination deserves even further limitation, the Producing Party may designate such Protected Material "RESTRICTED - ATTORNEYS' EYES ONLY," or to the extent such Protected Material includes extremely sensitive DESIGNATED MATERIAL representing computer source code and/or live data (that is, data as it exists residing in a database or databases) as well as associated "Readme" files that are stored in the same directory as the source code in the ordinary course of business (collectively, "Source Code Material"), the Producing Party may designate such Protected Material as "RESTRICTED CONFIDENTIAL - SOURCE CODE."

9. For Protected Material designated RESTRICTED - ATTORNEYS' EYES ONLY, access to, and disclosure of, such Protected Material shall be limited to individuals listed in paragraphs 5(a-c) and (e-g); provided, however, that access by in-house counsel pursuant to paragraph 5(c) be limited to in-house counsel who exercise no competitive decision-making authority on behalf of the client.

10. For Protected Material designated RESTRICTED CONFIDENTIAL - SOURCE CODE, the following additional restrictions apply:

(a) Access to a Party's Source Code Material shall be provided only on "stand-alone" computer(s) (that is, the computer may not be linked to any network, including a local area network ("LAN"), an intranet or the Internet) and on which all access ports have been disabled, as necessary and appropriate to prevent and protect

against any unauthorized copying, transmission, removal, or other transfer of any Source Code outside or away from the computer on which the Source Code is provided for inspection. Additionally, except as provided in paragraph 10(u) below, the stand-alone computer(s) may only be located at or near the offices of the Producing Party's Outside Counsel of Record or In-House Counsel of Record if the Party is not represented by outside counsel. The Producing Party may visually monitor the activities of the Receiving Party's representatives during any source code review, but only to ensure that there is no unauthorized recording, copying, or transmission of the source code;

(b) No recordable media or recordable devices, including without limitation sound recorders, computers, cellular telephones, peripheral equipment, cameras, CDs, DVDs, or drives of any kind shall be permitted into the source code review room.

(c) Parties shall ensure that appropriate software sufficient for viewing, and searching the Source Code Material is installed on the Secure Source Code Computers. The Receiving Party's counsel and/or experts may request that commercially available software for viewing, and searching source code be installed on the Secure Source Code Computer. The Receiving Party must provide the Producing Party with electronic media containing such software, or links to a public location from which such software may be downloaded, and any necessary licenses at least four (4) days in advance of the date upon which the Receiving Party wishes to have the software tools available for use on the Secure Source Code Computers. Examples of software may include SciTools Understand, Eclipse, Android Studio, Microsoft Visual Studio, Notepad++, UltraEdit, SlickEdit, Beyond Compare, CodeSuite from Software Analysis, PowerGrep, Mozilla Firefox, Adobe Acrobat, or other similar software that provides for viewing, and searching source code;

(d) The Receiving Party shall make reasonable efforts to restrict its requests for such access to the stand-alone computer(s) to normal business hours, which for purposes of this paragraph shall be 9:00 a.m. through 6:00 p.m. The Parties agree to cooperate in good faith such that maintaining the Producing Party's Source Code Material at or near the offices of its Outside Counsel of Record, or In-House Counsel of Record if the Party is not represented by outside counsel, shall not unreasonably hinder the Receiving Party's ability to efficiently and effectively conduct the prosecution or defense of this Action;

(e) The Producing Party shall provide the Receiving Party with information explaining how to start, log on to, and operate the stand-alone computer(s) in order to access the produced Source Code Material on the stand-alone computer(s);

(f) The Producing Party will produce Source Code Material in computer searchable format on the stand-alone computer(s) as described above;

(g) Access to Protected Material designated RESTRICTED CONFIDENTIAL -

SOURCE CODE shall be limited to Outside Counsel of Record and up to three (3) outside consultants or experts[2] (i.e., not existing employees or affiliates of a Party or an affiliate of a Party) retained for the purpose of this litigation and approved to access such Protected Materials pursuant to paragraph 5(e) above. A receiving Party may include excerpts of Source Code Material in a pleading, exhibit, expert report, discovery document, deposition transcript, other Court document, provided that the Source Code Documents are appropriately marked under this Order, restricted to those who are entitled to have access to them as specified herein, and, if filed with the Court, filed under seal in accordance with the Court's rules, procedures and orders;

(h) To the extent portions of Source Code Material are quoted in a Source Code Exhibit, either (1) the entire Source Code Exhibit will be stamped and treated as RESTRICTED CONFIDENTIAL - SOURCE CODE or (2) those pages containing quoted Source Code Material will be separately stamped and treated as RESTRICTED CONFIDENTIAL - SOURCE CODE and, if filed with the Court, filed under seal in accordance with the Court's rules, procedures, and orders;

(i) Except as set forth in paragraph 10(l) below, no electronic copies of Source Code Material shall be made without prior written consent of the producing Party, except as necessary to create documents which, pursuant to the Court's rules, procedures and order, must be filed or served electronically.

(j) The Receiving Party shall not be permitted to make its own printouts and photocopies of Source Code Material. At the Receiving Party's request, the Producing Party shall provide up to three (3) copies of all printouts of Source Code Material, all of which shall be designated and clearly labeled "RESTRICTED CONFIDENTIAL SOURCE CODE";

(k) If the Receiving Party's Outside Counsel of Record, consultants, or experts obtain printouts or photocopies of Source Code Material, the Receiving Party shall ensure that such outside counsel, consultants, or experts keep the printouts or photocopies in a secured locked area in the offices of such outside counsel, consultants, or expert. The Receiving Party may also temporarily keep the printouts or photocopies at: (i) the Court for any proceedings(s) relating to the Source Code Material, for the dates associated with the proceeding(s); (ii) the sites where any deposition(s) relating to the Source Code Material are taken, for the dates associated with the deposition(s); and (iii) any intermediate location reasonably necessary to transport the printouts or photocopies (*e.g.*, a hotel prior to a Court proceeding or deposition); and

(l) A Producing Party's Source Code Material may only be transported by the

[2] For the purposes of this paragraph, an outside consultant or expert is defined to include the outside consultant's or expert's direct reports and other support personnel, such that the disclosure to a consultant or expert who employs others within his or her firm to help in his or her analysis shall count as a disclosure to a single consultant or expert.

Receiving Party at the direction of a person authorized under paragraph 10(e) above to another person authorized under paragraph 10(e) above, on paper or removable encrypted electronic media (*e.g.*, a DVD, CD-ROM, or flash memory "stick") via hand carry, Federal Express or other similarly reliable courier. Source Code Material may not be transported or transmitted electronically over a network of any kind, including a LAN, an intranet, or the Internet. Source Code Material may only be transported electronically for the purpose of Court proceeding(s) as set forth in paragraph 10(k) above and is at all times subject to the transport restrictions set forth herein. But, for those purposes only, the Source Code Materials may be loaded onto a stand-alone computer.

Notes

(m) The Receiving Party's outside counsel of record and/or authorized consultants and experts pursuant to paragraph 5(g) above shall be entitled to take handwritten notes relating to the Source Code Material including identifying the file name and line number of the code, but may not copy entire lines of code. Such notes shall be labeled "RESTRICTED CONFIDENTIAL - SOURCE CODE." The Receiving Party shall be under no obligation to produce handwritten notes. No copies of all or any portion of the Source Code Material may leave the source code review room. The Receiving Party may take handwritten notes. All notes are protected by attorney client privilege. No other written or electronic record of the Source Code Material is permitted except as otherwise provided in this Protective Order.

(n) Unless otherwise agreed in advance by the parties in writing, the Receiving Party's authorized counsel and/or authorized consultants and experts pursuant to paragraph 5(g) above shall remove all notes, documents, and all other materials from the source code review room that may contain work product and/or attorney-client privileged information at the end of each day. Materials inadvertently left in the source code review room do not operate as a waiver of the attorney work product doctrine or any other applicable privilege and shall be returned to the owner promptly. The Producing Party shall not be responsible for any items left in the source code review room.

Printouts and Copies

(o) The Receiving Party may request a printout of reasonable portions of the Source Code Material. The Receiving Party shall not request the printouts of Source Code Material in order to review blocks of Source Code Material in the first instance (i.e., as an alternative to reviewing Source Code Material electronically on the source code computers) as the Parties acknowledge and agree that the purpose of the protections herein would be frustrated by printing portions of Source Code Material for review and analysis elsewhere.

(p) In the event that the Producing Party objects that identified files are not reasonably necessary, the Producing Party shall make such objection known to the Receiving

Party within three (3) business days of the identification of any files by the Receiving Party. The Producing Party will make itself available within three (3) business days of making the objection for a meet and confer. If, after meeting and conferring, the Producing Party and the Receiving Party cannot resolve the objection, the Producing Party shall seek a judicial resolution of whether or not the identified Source Code Material in question is reasonably necessary to any case preparation activity. The parties recognize that the volume and format of source code at issue in the case is unknown. Nevertheless, the Receiving Party will make a good faith effort to not exceed the agreed limit of fifteen (15) consecutive pages and an aggregate of more than six-hundred fifty (650) pages of printouts of Source Code Material. Requests to print additional pages beyond these limits will not be unreasonably withheld by the Producing Party. In the event Producing Party refuses a request to print additional pages, the Receiving Party will bear the burden of demonstrating the additional printouts are relevant to the needs of the case At the request of the Receiving Party, in the absence of any objection the Producing Party shall provide within five (5) days of such request, a printout of the Source Code Material requested by the Receiving Party. The Producing Party shall print and label such Source Code Material with the complete path name, if applicable, and append production numbers and the designation "RESTRICTED CONFIDENTIAL - SOURCE CODE."

(q) Unless agreed by the parties, images or copies of Source Code Material shall not be included in correspondence between the Parties (references to production numbers shall be used instead). The parties will make a good faith effort to omit or minimize the use of images or copies of Source Code Material in pleadings, exhibits, and other papers.

(r) The Receiving Party shall maintain a record of any individual who has inspected any portion of the Source Code Material in electronic or paper form. The log shall include the number of paper copies, names of the recipients of paper copies, and locations where the paper copies are stored. Upon three (3) business day's advance notice to the Receiving Party by the Producing Party, the Receiving Party shall provide a copy of this log to the Producing Party. The Parties agree the purpose of the log is to evidence compliance with this Order and that the log may not be used for examination of a witness. All copies of Source Code Material shall be printed with an "anti-copying" watermark that reveals whether such printouts have been photocopied.

(s) Consistent with and subject to paragraph 10(k) above, Source Code Material must be kept at all times in a secured, locked and hardened container (e.g., a safe or lockbox) that prevents duplication of or unauthorized access to the Source Code Material.

Depositions

(t) For all depositions, Receiving Party may request that the witness have access to a

Secure Source Code Computer during the deposition three (3) days prior to the deposition. Upon such request, Producing Party will ensure a Secure Source Code Computer is available with all code during examination with reasonable search tools so that the witness can be questioned about the code. If a Source Code Material document has been marked up or altered in any way by the deponent, the Producing Party shall copy the exhibit in its marked form and provide one copy to outside counsel for the Receiving Party. Copies of Source Code Material that are marked as deposition exhibits shall not be provided to the Court Reporter or attached to deposition transcripts; rather, the deposition record will identify the exhibit by its production numbers.

11. Any attorney representing a Party, whether in-house or outside counsel, and any person associated with a Party that receives the other Party's Protected Material that is designated RESTRICTED - ATTORNEYS' EYES ONLY and/or RESTRICTED CONFIDENTIAL - SOURCE CODE (collectively "HIGHLY SENSITIVE MATERIAL"), who obtains, receives, has access to, or otherwise learns, in whole or in part, HIGHLY SENSITIVE MATERIAL under this Order shall not prepare, prosecute, supervise, or assist in the preparation or prosecution of any patent application pertaining to the field of the invention of the patents-in-suit on behalf of the Receiving Party or its acquirer, successor, predecessor, or other affiliate during the pendency of this Action and for one year after its conclusion, including any appeals. This provision does not prohibit a Party's counsel of record or experts in this litigation from participating in or representing it in reexamination proceedings, Post-Grant Review proceedings, Inter Partes Review proceedings, or Covered Business Method Review proceedings involving any patent, including the patents-in-suit, provided they do not advise on, consult on, prepare, draft, edit, or otherwise provide input into any claims, or amendment to specifications or claims in those proceedings. To ensure compliance with the purpose of this provision, each Party shall create an "Ethical Wall" between those persons with access to HIGHLY SENSITIVE MATERIAL and any individuals who, on behalf of the Party or its acquirer, successor,

predecessor, or other affiliate, prepare, prosecute, supervise or assist in the preparation or prosecution of any patent application pertaining to the field of invention of the patent-in-suit.

12. Unless otherwise provided by this Order or provided by the Court, confidentiality obligations imposed by this Order shall remain in effect following the conclusion of this lawsuit.

13. Nothing in this Order shall require production of documents, information or other material that a Party contends is protected from disclosure by the attorney-client privilege, the work product doctrine, or other privilege, doctrine, or immunity. If documents, information or other material subject to a claim of attorney-client privilege, work product doctrine, or other privilege, doctrine, or immunity is inadvertently or unintentionally produced, such production shall in no way prejudice or otherwise constitute a waiver of, or estoppel as to, any such privilege, doctrine, or immunity. Any Party that inadvertently or unintentionally produces documents, information or other material it reasonably believes are protected under the attorney-client privilege, work product doctrine, or other privilege, doctrine, or immunity may obtain the return of such documents, information or other material by promptly notifying the recipient(s) and providing a privilege log for the inadvertently or unintentionally produced documents, information or other material. The recipient(s) shall gather and return all copies of such documents, information or other material to the Producing Party, except for any pages containing privileged or otherwise protected markings by the recipient(s), which pages shall instead be destroyed and certified as such to the Producing Party. If a Receiving Party believes that a produced document or other information may reasonably be subject to a claim of privilege, then the Receiving Party

shall promptly inform the Producing Party of the beginning BATES number of the document or, if no BATES number is available, shall otherwise inform the Producing Party of the information.

14. There shall be no disclosure of any DESIGNATED MATERIAL by any person authorized to have access thereto to any person who is not authorized for such access under this Order. The Parties are hereby ORDERED to safeguard all such documents, information and material to protect against disclosure to any unauthorized persons or entities.

15. Nothing contained herein shall be construed to prejudice any Party's right to use any DESIGNATED MATERIAL in taking testimony at any deposition or hearing provided that the DESIGNATED MATERIAL is only disclosed to a person(s) who is: (i) eligible to have access to the DESIGNATED MATERIAL by virtue of his or her employment with the designating party, (ii) identified in the DESIGNATED MATERIAL as an author, addressee, or copy recipient of such information, (iii) although not identified as an author, addressee, or copy recipient of such DESIGNATED MATERIAL, has, in the ordinary course of business, seen such DESIGNATED MATERIAL, (iv) a current or former officer, director or employee of the Producing Party or a current or former officer, director or employee of a company affiliated with the Producing Party; (v) counsel for a Party, including outside counsel and in-house counsel (subject to paragraph 9 of this Order); (vi) an independent contractor, consultant, and/or expert retained for the purpose of this litigation; (vii) court reporters and videographers; (viii) the Court; or (ix) other persons entitled hereunder to access to DESIGNATED MATERIAL. DESIGNATED MATERIAL shall not be disclosed to any other persons unless prior authorization is obtained from counsel representing the Producing Party or from the Court.

16. Parties may, at the deposition or hearing or within thirty (30) days after receipt of a deposition or hearing transcript, designate the deposition or hearing transcript or any portion thereof as "CONFIDENTIAL," "RESTRICTED - ATTORNEY' EYES ONLY," or "RESTRICTED CONFIDENTIAL - SOURCE CODE" pursuant to this Order. Access to the deposition or hearing transcript so designated shall be limited in accordance with the terms of this Order. Until expiration of the 30-day period, the entire deposition or hearing transcript shall be treated as confidential.

17. Any DESIGNATED MATERIAL that is filed with the Court shall be filed under seal and shall remain under seal until further order of the Court. The filing party shall be responsible for informing the Clerk of the Court that the filing should be sealed and for placing the legend "FILED UNDER SEAL PURSUANT TO PROTECTIVE ORDER" above the caption and conspicuously on each page of the filing. Exhibits to a filing shall conform to the labeling requirements set forth in this Order. If a pretrial pleading filed with the Court, or an exhibit thereto, discloses or relies on confidential documents, information or material, such confidential portions shall be redacted to the extent necessary and the pleading or exhibit filed publicly with the Court.

18. The Order applies to pretrial discovery. Nothing in this Order shall be deemed to prevent the Parties from introducing any DESIGNATED MATERIAL into evidence at the trial of this Action, or from using any information contained in DESIGNATED MATERIAL at the trial of this Action, subject to any pretrial order issued by this Court.

19. A Party may request in writing to the other Party that the designation given to any DESIGNATED MATERIAL be modified or withdrawn. If the designating Party does not agree to redesignation within ten (10) days of receipt of the written request, the requesting

Party may apply to the Court for relief. Upon any such application to the Court, the burden shall be on the designating Party to show why its classification is proper. Such application shall be treated procedurally as a motion to compel pursuant to Federal Rules of Civil Procedure 37, subject to the Rule's provisions relating to sanctions. In making such application, the requirements of the Federal Rules of Civil Procedure and the Local Rules of the Court shall be met. Pending the Court's determination of the application, the designation of the designating Party shall be maintained.

20. Each outside consultant or expert to whom DESIGNATED MATERIAL is disclosed in accordance with the terms of this Order shall be advised by counsel of the terms of this Order, shall be informed that he or she is subject to the terms and conditions of this Order, and shall sign an acknowledgment that he or she has received a copy of, has read, and has agreed to be bound by this Order. A copy of the acknowledgment form is attached as Appendix A.

21. To the extent that any discovery is taken of persons who are not Parties to this Action ("Third Parties") and in the event that such Third Parties contended the discovery sought involves trade secrets, confidential business information, or other proprietary information, then such Third Parties may agree to be bound by this Order.

22. To the extent that discovery or testimony is taken of Third Parties, the Third Parties may designate as "CONFIDENTIAL" or "RESTRICTED - ATTORNEYS' EYES ONLY" any documents, information or other material, in whole or in part, given by such Third Parties. The Third Parties shall have ten (10) days after production of such documents, information or other materials to make such a designation. Until that time period lapses or until such a designation has been made, whichever occurs sooner, all documents, information or other

material so produced or given shall be treated as "CONFIDENTIAL" in accordance with this Order.

23. Within sixty (60) days of final termination of this Action, including any appeals, all DESIGNATED MATERIAL, including all copies, duplicates, abstracts, indexes, summaries, descriptions, and excerpts or extracts thereof (excluding excerpts or extracts incorporated into any privileged memoranda of the Parties and materials which have been admitted into evidence in this Action), shall at the Producing Party's election either be returned to the Producing Party or be destroyed. No copies shall be retained by a Receiving Party or other individuals retained to assist them in this litigation, except counsel may retain copies of pleadings in their files and the terms of this Protective Order shall continue to apply to such copies. The language contained in this paragraph shall not preclude counsel from retaining documents constituting attorney work product as defined by applicable law, or from retaining one copy of all such work product documents as part of a permanent litigation file that is otherwise subject to the confidentiality restrictions set forth herein. The Receiving Party shall verify the return or destruction by affidavit furnished to the Producing Party, upon the Producing Party's request. Nothing in this order requires a Party to destroy any information it is required by law to retain. The Parties shall not be required to delete information that may reside on electronic disaster recovery systems that are overwritten in the normal course of business, or information that may reside in electronic files which are not reasonably accessible. However, parties and their Counsel shall not retrieve, access, nor use any Protected Material from said electronic disaster recovery systems or other not-reasonably accessible data sources after the conclusion of the matter. The parties shall make a good faith effort to locate and destroy any case materials

designated RESTRICTED CONFIDENTIAL - SOURCE CODE.

24. The failure to designate documents, information or material in accordance with this Order and the failure to object to a designation at a given time shall not preclude the filing of a motion at a later date seeking to impose such designation or challenging the propriety thereof. The entry of this Order and/or the production of documents, information and material hereunder shall in no way constitute a waiver of any objection to the furnishing thereof, all such objections being hereby preserved.

25. Any Party knowing or believing that any other party is in violation of or intends to violate this Order and has raised the question of violation or potential violation with the opposing party and has been unable to resolve the matter by agreement may move the Court for such relief as may be appropriate in the circumstances. Pending disposition of the motion by the Court, the Party alleged to be in violation of or intending to violate this Order shall discontinue the performance of and/or shall not undertake the further performance of any action alleged to constitute a violation of this Order.

26. Production of DESIGNATED MATERIAL by each of the Parties shall not be deemed a publication of the documents, information and material (or the contents thereof) produced so as to void or make voidable whatever claim the Parties may have as to the proprietary and confidential nature of the documents, information or other material or its contents.

27. The Receiving Party may not upload to, share with, or otherwise use DESIGNATED MATERIAL of the Producing Party on any generative artificial intelligence (GenAI) or large language model (LLM) tools or platforms including any third-party, public, or internal tools unless the Producing Party approves the use of such tool or the Court issues an Order approving the use of such tool upon request by the Receiving Party.

28. Nothing in this Order shall be construed to effect an abrogation, waiver or limitation of any kind on the rights of each of the Parties to assert any applicable discovery or trial privilege.

29. Each of the Parties shall also retain the right to file a motion with the Court (a) to modify this Order to allow disclosure of DESIGNATED MATERIAL to additional persons or entities if reasonably necessary to prepare and present this Action and (b) to apply for additional protection of DESIGNATED MATERIAL.

So ORDERED and SIGNED this 21st day of November, 2025.

RODNEY GILSTRAP
UNITED STATES DISTRICT JUDGE

IN THE UNITED STATES DISTRICT COURT
FOR THE EASTERN DISTRICT OF TEXAS
MARSHALL DIVISION

PERCEPTIVE AUTOMATA LLC, *Plaintiff,*	§ §	
v.	§ §	Case No. 2:25-cv-00742-JRG
TESLA, INC., *Defendant.*	§ § §	JURY TRIAL DEMANDED

APPENDIX A
UNDERTAKING OF EXPERTS OR CONSULTANTS REGARDING PROTECTIVE ORDER

I, _____, declare that:

1. My address is _____.

   My current employer is _____.

   My current occupation is _____.

2. I have received a copy of the Protective Order in this action. I have carefully read and understand the provisions of the Protective Order.

3. I will comply with all of the provisions of the Protective Order. I will hold in confidence, will not disclose to anyone not qualified under the Protective Order, and will use only for purposes of this action any information designated as "CONFIDENTIAL," "RESTRICTED - ATTORNEYS' EYES ONLY," or "RESTRICTED CONFIDENTIAL - SOURCE CODE" that is disclosed to me.

4. Promptly upon termination of these actions, I will return all documents and things designated as "CONFIDENTIAL," "RESTRICTED - ATTORNEYS' EYES ONLY," or "RESTRICTED CONFIDENTIAL - SOURCE CODE" that came into my possession,

and all documents and things that I have prepared relating thereto, to the outside counsel for the party by whom I am employed.

5. I hereby submit to the jurisdiction of this Court for the purpose of enforcement of the Protective Order in this action.

I declare under penalty of perjury that the foregoing is true and correct.

Signature _____

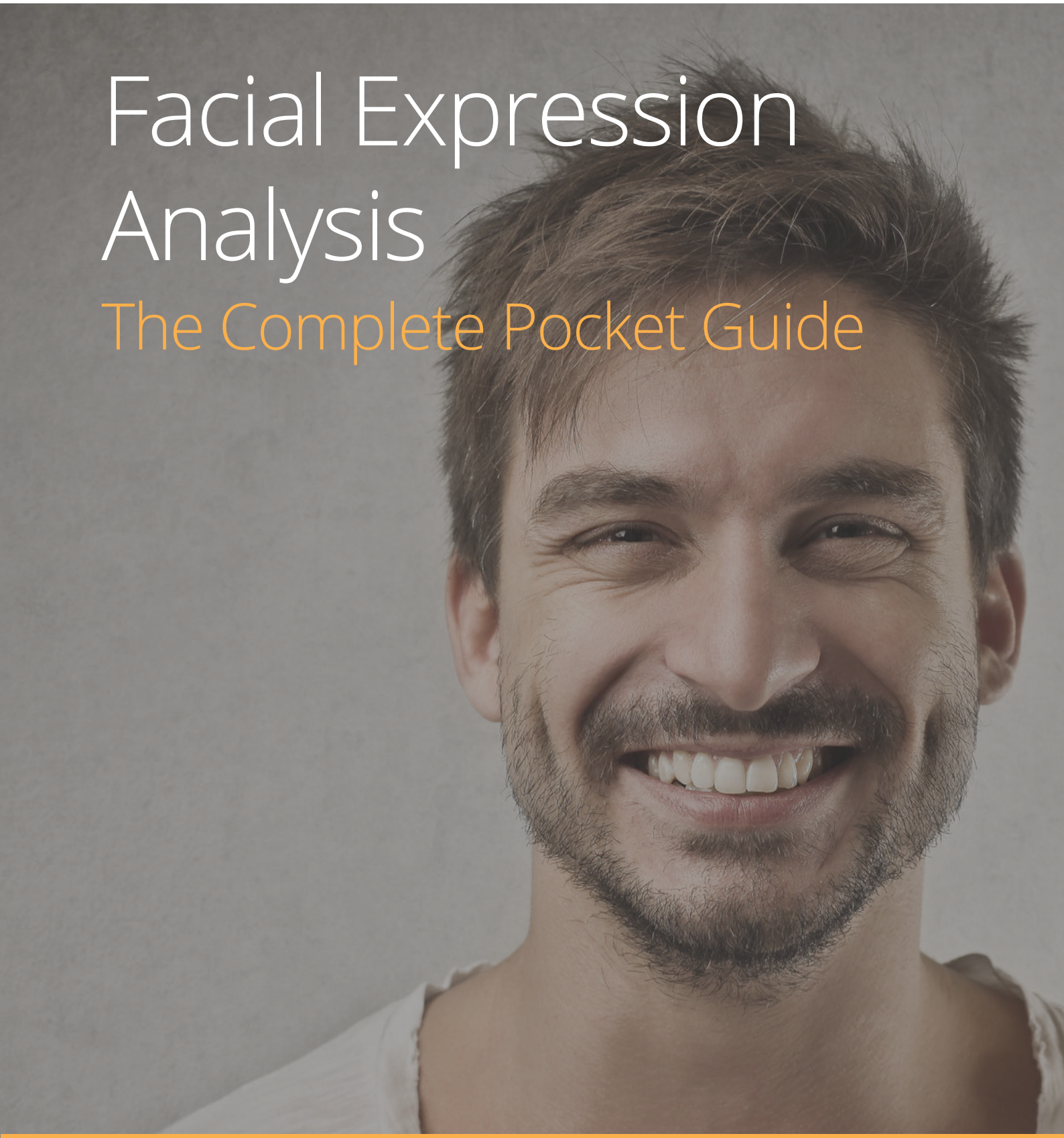
Date _____

Attachment C

IMOTIONS®

Facial Expression Analysis

The Complete Pocket Guide



iMotions – Biometric Research, Simplified

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The definitive guide

Emotions are the essence of what makes us human. They impact our daily routines, our social interactions, our attention, perception, and memory.

One of the strongest indicators for emotions is our face. As we laugh or cry we're putting our emotions on display, allowing others to glimpse into our minds as they „read" our face based on changes in key face features such as eyes, brows, lids, nostrils, and lips.

Computer-based facial expression analysis mimics our human coding skills quite impressively as it captures raw, unfiltered emotional responses towards any type of emotionally engaging content. But how exactly does it work?

We have the answers. This definitive guide is all you need to get the knack of facial coding and research into the quality of emotional behavior. Now is the right time to get started.

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IMOTIONS®
BIOMETRIC RESEARCH PLATFORM

The basics … and beyond

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What are facial expressions?

Our face is an intricate, highly differentiated part of our body - in fact, it is one of the most complex signal systems available to us. It includes over 40 structurally and functionally autonomous muscles, each of which can be triggered independently of each other.

The facial muscular system is the only place in our body where muscles are either attached to a bone *and* facial tissue (other muscles in the human body connect to two bones), or to facial tissue only such as the muscle surrounding the eyes or lips.

Obviously, facial muscle activity is highly **specialized for expression** - it allows us to share social information with others and communicate both verbally and nonverbally.

...did you know?

Almost all facial muscles are triggered by one single nerve - the **facial nerve**. There is one exception, though: The upper eyelid is innervated by the **oculomotor nerve**, which is responsible for a great part of eye movements, pupil contractions, and raising the eyelid.

The facial nerve controls the majority of facial muscles

All muscles in our body are innervated by nerves, which route all the way into the spinal cord and brain. The nerve connection is bidirectional, which means that the nerve is triggering muscle contractions based on brain signals (brain-to-muscle), while it at the same time communicates information on the current muscle state back to the brain (muscle-to-brain).

What are facial expressions?

Facial expressions are movements of the numerous muscles supplied by the facial nerve that are attached to and move the facial skin.

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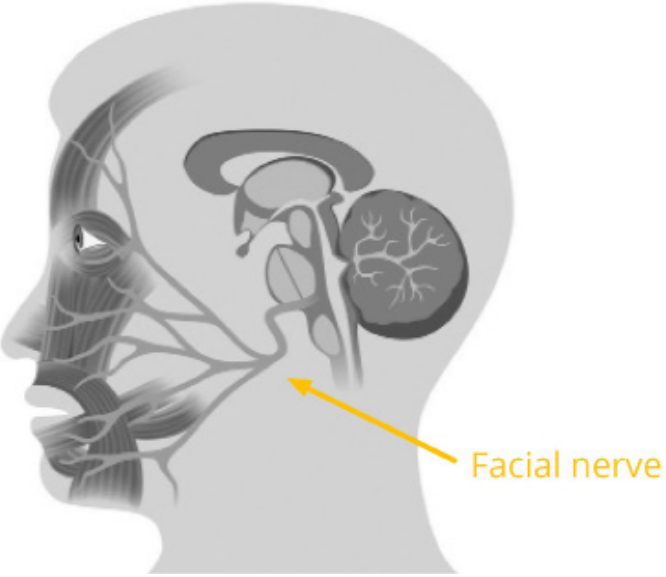
Almost all facial muscles are innervated by a single nerve, therefore simply referred to as **facial nerve**.

In slightly more medical terms, the facial nerve is also known under "VII. cranial nerve".



The facial nerve emerges from deep within the **brainstem**, leaves the skull slightly below the ear, and branches off to all muscles like a tree. Interestingly, the facial nerve is also wired up with much younger motor regions in our neo-cortex (neo as these areas are present only in mammalian brains), which are primarily responsible for facial muscle movements required for talking.

...did you know?

As the name indicates, the **brainstem** is an evolutionary very ancient brain area which humans share with almost all living animals.

Voluntary and involuntary facial expressions

Brainstem and motor cortex are specifically active dependent on whether a facial expression is **involuntary** or **voluntary**.

While the brainstem controls involuntary and unconscious expressions that occur spontaneously, the motor cortex is involved in consciously controlled and intentional facial expressions.

Exactly this is the reason why a fake smile just doesn't appear natural, whereas a genuine smile most likely does. You might even realize another effect: Faking a smile doesn't even *feel* right! Obviously, it doesn't trigger the same emotional reactions in your body compared to an authentic smile.

To understand this effect, take a closer look at the interaction between facial expressions and emotions in the next chapter.

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Facial expressions & emotions

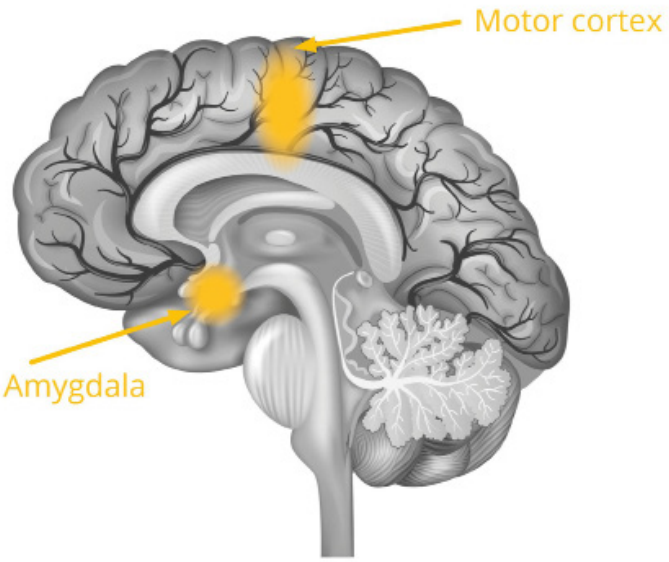
So far we know that the facial nerve connects the majority of muscles in the face with the brain. Now how does this relate to emotions and emotional behavior?

Actually, the very same regions in the brainstem that trigger our facial expressions control emotional processing and regulation.

Functional imaging studies (fMRI) have identified one specific region in the brainstem to be highly active when confronted with potential visual or auditory threats (a looming shadow or a high-pitched scream, for example):
The right and left **amygdala**.

The amygdala controls emotional arousal

Often, the **amygdala** is associated with processing of live-threatening, fearful events or stimuli of high sexual appeal and bodily pleasure. Besides fear and pleasure processing, the amygdala has been found to be generally responsible for autonomic functions associated with emotional arousal.



...did you know?

The **amygdala** modulates the emission of cortisol and other stress hormones into the bloodstream, controls heart rate, skin conductance and respiration as well as observable behaviors such as changes in posture and – via the facial nerve – facial expressions.

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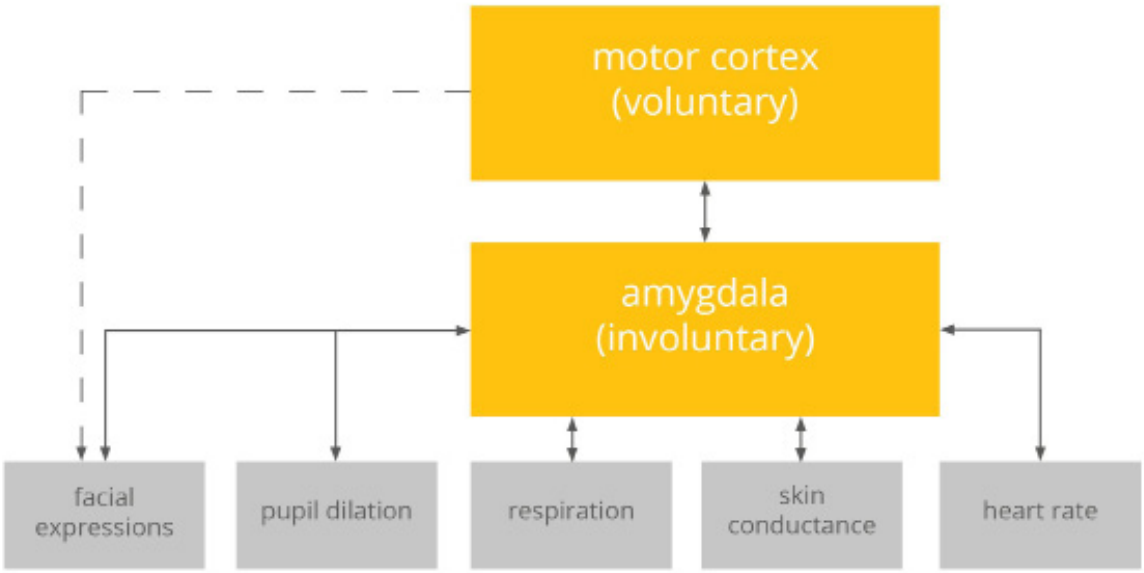

The facial feedback hypothesis

As ingeniously discovered by *Fritz Strack and colleagues* in 1988, facial expressions and emotions are closely intertwined. In their study, respondents were asked to hold a pen in their mouths while rating cartoons for their humor content. While one group held the pen between their teeth with lips open (mimicking a smile), the other group held the pen with their lips only (preventing a proper smile).

Here's what Fritz Strack found out: The first group rated the cartoon as more humorous. Strack and team took this as evidence for the **facial feedback hypothesis** postulating that selective activation or inhibition of facial muscles has a strong impact on the emotional response to stimuli.

Emotions, feeling, moods

What exactly are emotions?

In everyday language, emotions are any relatively brief conscious experiences characterized by intense mental activity and a high degree of pleasure or displeasure. In scientific research, a consistent definition has not been found yet. There's certainly conceptual overlaps between the psychological and neuroscientific underpinnings of emotions, moods, and feelings.

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Emotions are closely linked to physiological and psychological arousal with various levels of arousal relating to specific emotions. In neurobiological terms, emotions could be defined as **complex action programs** triggered by the presence of certain external or internal stimuli.

These action programs contain the following elements:

1. **Bodily symptoms** such as increased heart rate or skin conductance. Mostly, these symptoms are unconscious and involuntary.
2. **Action tendencies**, for example “fight-or-flight” actions to either immediately evade from a dangerous situation or to prepare a physical attack of the opponent.
3. **Facial expressions**, for example baring one’s teeth and frowning.
4. **Cognitive evaluations** of events, stimuli or objects.

Emotions vs. feelings vs. moods

Feelings are subjective perceptions of the emotional action programs. Feelings are driven by conscious thoughts and reflections - we surely can have emotions without having feelings, however we simply cannot have feelings without having emotions.

Moods are diffuse internal, subjective states, generally being less intense than emotions and lasting significantly longer. Moods are highly affected by personality traits and characteristics. Voluntary facial expressions (smiling, for example) can produce bodily effects similar to those triggered by an actual emotion (happiness,

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Can you classify emotions?

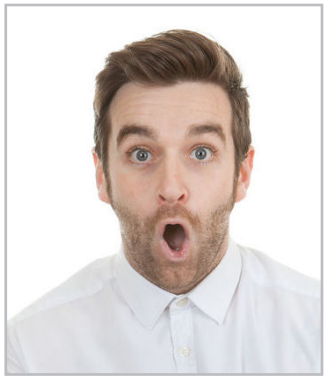
Facial expressions are only one out of many correlates of emotion, but they might be the most apparent ones. Humans are obviously able to produce thousands of slightly varying sets of facial expressions – however, there is only a small set of distinctive facial configurations that almost every one associates with certain emotions, irrespective of gender, age, cultural background and socialization history.

These categorical emotions are:

Joy

Anger

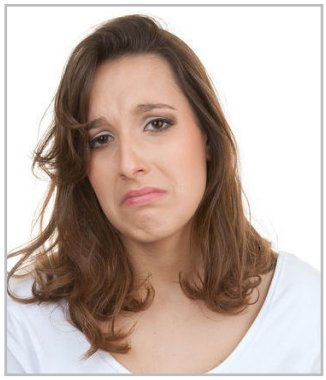
Surprise



Fear

Contempt

Sadness



Disgust

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The finding that almost everyone can produce and recognize the associated facial expressions of these emotions has led researchers to the assumption that they are universal.

There is an ongoing discussion in emotion research on how the different emotions could be distinguished from each other:

1 **Discrete emotion theory** assumes that the seven basic emotions are mutually exclusive, each with different action programs, facial expressions, physiological processes, and accompanying cognitions.

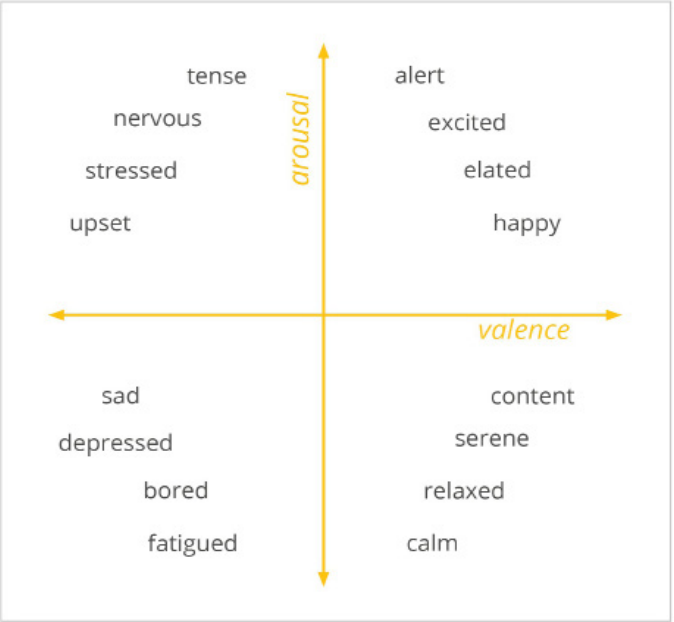
2 **Dimensional models** assume that emotions can be grouped and arranged along two or more dimensions. Most dimensional models use **valence** (positive vs. negative emotions) as horizontal axis and **arousal** (activating vs. calming emotions) as vertical axis.

With valence and arousal, more subtle emotional classifications are possible - breaking "happiness" into a less aroused "happy" state and a more aroused "elated" state, for example. Again, facial expressions are core indicators of underlying emotional states.

...did you know?

Testing *Darwin's* "universality hypothesis" from 1872, *Ekman & Friesen* conducted a cross-cultural study in 1987 where respondents watched pictures of human faces and were asked to classify which emotion was present and rate the intensity of the emotion.

All respondents were able to classify which emotion was active (while minor cultural variations existed in ratings of emotional intensity).



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Application fields

With facial expression analysis you can test the impact of **any content, product or service** that is supposed to elicit emotional arousal and facial responses - physical objects such as food probes or packages, videos and images, sounds, odors, tactile stimuli, etc. Particularly involuntary expressions as well as a subtle widening of the eyelids are of key interest as they are considered to reflect changes in the emotional state triggered by actual external stimuli or mental images.

Now which fields of commercial and academic research have been adopting facial expression analysis techniques lately? Here is a peek at the most prominent research areas:

...did you know?

Humans are processing visual information to a much larger extent than other senses - we might get just as thrilled by watching a video of a rollercoaster ride as we get by actually riding it.

Needless to say that immersive digital media content, video games, and software interfaces constitute a new generation of visual stimuli that elicit facial responses.

1 Consumer neuroscience and neuromarketing

There is no doubt about it: Evaluating consumer preferences and delivering persuasive communication are critical elements in marketing. While self-reports and questionnaires might be ideal tools to get insights into respondents' attitudes and awareness, they might be limited in capturing emotional responses unbiased by self-awareness and social desirability. That's where the value of facial analysis comes in: Tracking facial expressions can be leveraged to substantially enrich self-reports with quantified measures of more unconscious emotional responses towards a product or service. Based on facial expression analysis, products can be optimized, market segments can be assessed, and target audiences and personas can be identified. There's quite a lot that facial expression analysis can do for you to enhance your marketing strategy - just think about it!

2 Media testing & advertisement

In media research, individual respondents or focus groups can be exposed to TV advertisements, trailers, and full-length pilots while monitoring their facial expressions. Identifying scenes where emotional responses (particularly smiles) were expected but the audience just didn't "get it" is as crucial as to find the key frames that result in the most extreme facial expressions.

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In this context, you might want to isolate and improve scenes that trigger unwanted negative expressions indicating elevated levels of disgust, frustration or confusion (those kind of emotions wouldn't exactly help a comedy show to become a hit series, would they?) or utilize your audience's response towards a screening in order to increase the overall level of positive expressions in the final release.

3 Psychological research

Psychologists analyze facial expressions to identify how humans respond emotionally towards external and internal stimuli. In systematic studies, researchers can specifically vary stimulus properties (color, shape, duration of presentation) and social expectancies in order to evaluate how personality characteristics and individual learning histories impact facial expressions.

...did you know?

The more similar your interaction partners appear to you (and the more you can relate to them), the more likely you are to take over their facial expressions.

4 Clinical psychology and psychotherapy

Clinical populations such as patients suffering from Autism Spectrum Disorder (ASD), depression or borderline personality disorder (BPD) are characterized by strong impairments in modulating, processing, and interpreting their own and others' facial expressions. Monitoring facial expressions while patients are exposed to emotionally arousing stimuli or social cues (faces of others, for example) can significantly boost the success of the underlying cognitive-behavioral therapy, both during the diagnostic as well as the intervention phase. An excellent example is the "Smile Maze" as developed by the Temporal Dynamics of Learning Center (TDLC) at UC San Diego. Here, autistic children train their facial expressions by playing a Pacman-like game where smiling steers the game character.

5 Medical applications & plastic surgery

The effects of facial nerve paralysis can be devastating. Causes include Bell's Palsy, tumors, trauma, diseases, and infections. Patients generally struggle with significant changes in their physical appearance, the ability to communicate, and to express emotions. Facial expression analysis can be used to quantify the deterioration and evaluate the success of surgical interventions, occupational and physical therapy targeted towards reactivating the paralyzed muscle groups.

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6 Software UI & website design

Ideally, handling software and navigating websites should be a pleasant experience - frustration and confusion levels should certainly be kept as low as possible. Monitoring facial expressions while testers browse websites or software dialogs can provide insights into the emotional satisfaction of the desired target group. Whenever users encounter road blocks or get lost in complex sub-menus, you might certainly see increased “negative” facial expressions such as brow furrowing or frowning.

7 Engineering of artificial social agents (avatars)

Until recently, robots and avatars were programmed to respond to user commands based on keyboard and mouse input. Latest breakthroughs in hardware technology, computer vision, and machine learning have laid the foundation for artificial social agents, who are able to reliably detect and flexibly respond to emotional states of the human communication partner. Apple’s Siri might be the first generation of emotionally truly intelligent machines, however computer scientists, physicians, and neuroscientists all over the world are working hard on even smarter sensors and algorithms to understand the current emotional state of the human user, and to respond appropriately.

...did you know?

As a matter of fact, facial expressions are also triggered by mentalizations, memories, and thoughts.Telling your best friend of your recent vacation in Hawaii might put a bright smile on your face, whereas thinking of next Monday morning (and the alarm going off at 6am) most likely will make you frown.

The variety of application fields for facial expression analysis is incredibly wide, which might be due to the fact that it is surprisingly simple to collect, process, and analyze high-quality facial muscle activity from optimally placed sensors in order to decode involuntary emotional reactions and uncover the subconscious processes driving emotional behavior.

But how exactly can facial expressions be collected?

We’ll get to it now.

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Facial expression analysis techniques

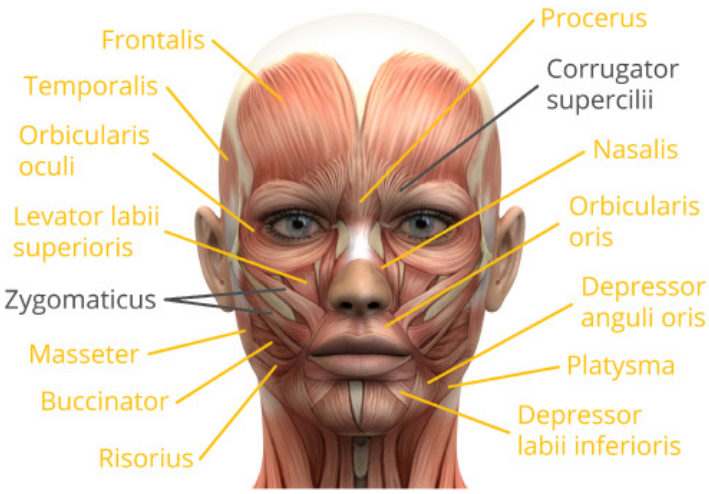
Facial expressions can be collected and analyzed in three different ways:

1. By tracking of facial electromyographic activity (fEMG)
2. By live observation and manual coding of facial activity
3. By automatic facial expression analysis using computer-vision algorithms

Let's explain them in more detail.

Facial electromyography (fEMG)

With facial EMG you can track the activity of facial muscles with electrodes attached to the skin surface. fEMG detects and amplifies the tiny electrical impulses generated by the respective muscle fibers during contraction. The most common fEMG sites are in proximity to the following two major muscle groups:



1 Right/left corrugator supercilii ("eyebrow wrinkler")

This is a small, narrow, pyramidal muscle near the eye brow, generally associated with frowning. The corrugator draws the eyebrow downward and towards the face center, producing a vertical wrinkling of the forehead. This muscle group is active to prevent high sun glare or when expressing negative emotions such as suffering.

2 Right/left zygomaticus (major)

This muscle extends from each cheekbone to the corners of the mouth and draws the angle of the mouth up and out, typically associated with smiling.

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Benefits of fEMG:

1 fEMG is a non-invasive, precise, sensitive method to continuously measure facial muscle activity.

2 fEMG does not depend upon language and does not require cognitive effort or memory.

3 fEMG is able to measure even very subtle facial muscle activity even in scenarios where respondents are instructed to inhibit their emotional expression.

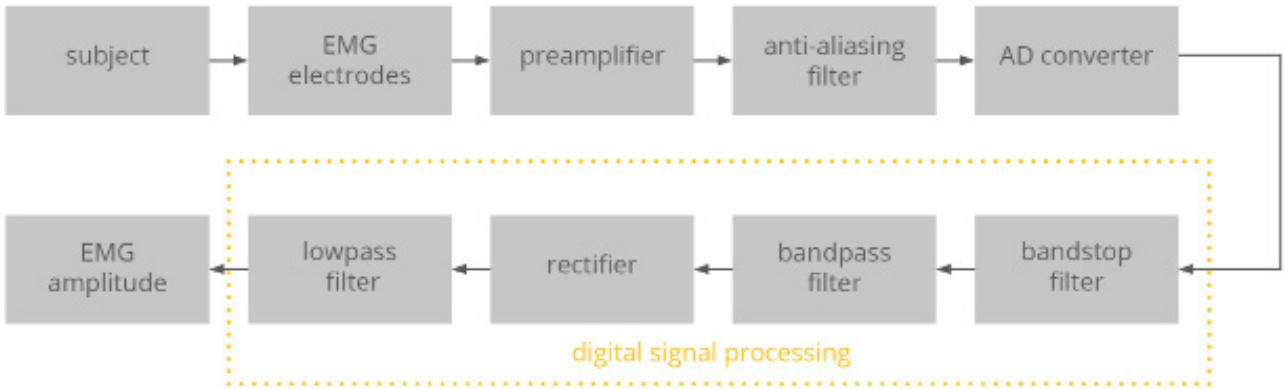
Limitations of fEMG:

1 fEMG requires electrodes, cables, and amplifiers. It therefore is intrusive, heightening the respondents' awareness of what is being measured.

2 fEMG is sensitive to motion artifacts and electrical interference.

3 fEMG analysis requires expert biosensor processing skills.

Here's how a biosensor processing pipeline for fEMG looks like:



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The Facial Action Coding System (FACS)

Based on the work of Swedish anatomist *Carl-Herman Hjortsjö*, *Paul Ekman* and *Wallace V. Friesen* developed one of the most influential methods to objectively code facial behavior in 1978, which was further fine-tuned in 2002.

Their approach named the **Facial Action Coding System (FACS)** represents a fully standardized classification system of facial expressions for expert human coders based on anatomic features. Experts carefully examine face videos and describe any occurrence of facial expressions as combinations of elementary components called **Action Units** (AUs).

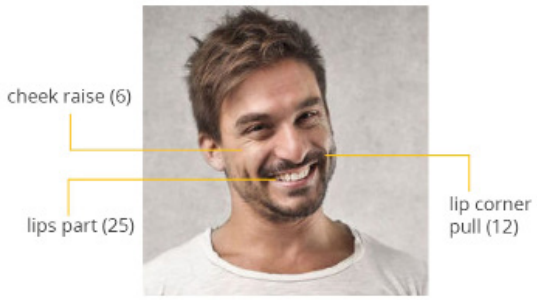
A common misbelief is that FACS is related to reading or detecting emotions. In fact, FACS is just a measurement system and does not interpret the meaning of the expressions. It's like saying the purpose of riding a bike is to go to work. Sure, you can ride a bike to work, but you can use your bike for a lot of other things as well (for leisure, sports training, etc.). You get the idea.

However, during the analytical phase, the FACS system allows for a modular construction of emotions based on the combination of AUs.

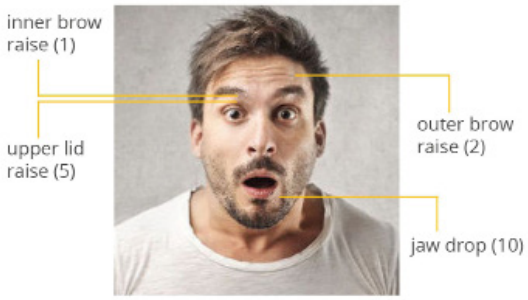
...did you know?

Each AU corresponds to an individual face muscle or muscle group. It is identified by a number (AU1, AU2, etc.). All facial expressions can be broken down into their constituent AUs. Assumed that facial expressions are "words", AUs are the "letters" that make up those words.

Happy



Surprised



With facial action unit coding you can get all the knowledge to dissociate between the following three facial expression categories:

1. **Macroexpressions** typically last between 0.5 - 4 seconds, occur in daily interactions, and generally are obvious to the naked eye.

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2 **Microexpressions** last less than half a second, occur when trying to consciously or unconsciously conceal or repress the current emotional state. Microexpressions are much harder to be detected; however, with a reasonable amount of training you can become an expert coder for microexpressions.

3 **Subtle expressions** are associated with the intensity and depth of the underlying emotion. We're fur sure not perpetually smiling or raising eyebrows – the intensity of these facial actions constantly varies. Subtle expressions denote any onset of a facial expression where the intensity of the associated emotion is still considered low.

Benefits of FACS:

1 Facial action coding is a non-intrusive, objective, reliable method to describe facial expressions. Emotional interpretations emerge only during the data processing stage.

2 FACS scores have a high face validity as they are based on visible changes in facial tissue.

3 FACS scores also contain a 5-step intensity rating (A, "trace", to E, "maximum").

Limitations of FACS:

1 FACS coding requires high quality video equipment.

2 FACS scoring relies on the trained discrimination of experts, rendering the coding very laborious and expensive. A well-trained FACS coder can easily take about 100 minutes to code 1 minute of video data depending on the density and complexity of facial actions.

3 FACS training itself is resource-intense, requiring about 100 hours of studying the FACS manual, and about 12 hours to take the FACS certification.

Out of these limitations, a new generation of facial expression technologies has emerged being fully automated and computer-based.

Sounds exciting? It sure is. Let's dig deeper into the specific requirements, data outputs, and analysis techniques of these as well as their pros and cons in the following chapters.

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IMOTIONS®
BIOMETRIC RESEARCH PLATFORM

Getting started with facial expression analysis

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Technology

Built on groundbreaking research of core academic institutions in the United States and Europe, automatic facial coding procedures have been developed and made available to the broader public, instantaneously detecting faces, coding facial expressions, and recognizing emotional states.

This breakthrough has been mainly enabled by the adoption of state-of-the-art computer vision and machine learning algorithms along with the gathering of high-quality databases of facial expressions all across the globe.

These technologies use cameras embedded in laptops, tablets, and mobile phones or standalone webcams mounted to computer screens to capture videos of respondents as they are exposed to content of various categories.
The use of inexpensive webcams eliminates the requirement for specialized high-class devices, making automatic expression coding ideally suited to capture face videos in a wide variety of naturalistic environmental settings such as respondents' homes, workplace, car, public transportation, and many more.

...did you know?

Automated facial coding has revolutionized the field of affective neuroscience and biosensor engineering, making emotion analytics and insights commercially available to the scientific community, commercial applications, and the public domain.

What exactly are the scientific and technological procedures under the hood of this magic black box?

Let's find out now.

The technology behind automatic facial coding

More or less, all facial expression analysis engines comprise the same steps.
Emotient FACET, for example, applies the following:

1. Face detection
2. Facial landmark detection and registration
3. Facial expression and emotion classification

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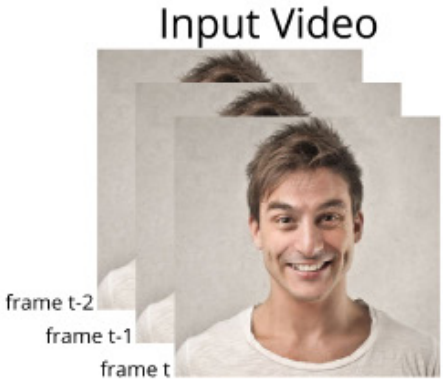
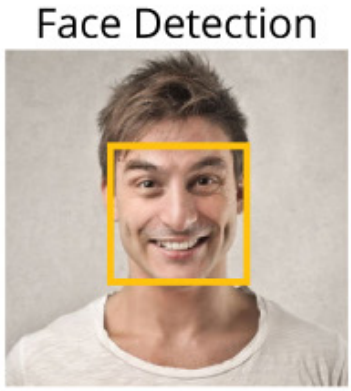
1 Face detection

The position of a face is found in a video frame or image, which can be achieved by applying the **Viola Jones Cascaded Classifier** algorithm, for example. This might sound sophisticated, but you can actually find this technology in the camera of your iPhone or Android smartphone as well. The result is a face box framing the detected face.



2 Feature detection

Within the detected face, facial landmarks such as eyes and eye corners, brows, mouth corners, the nose tip etc. are detected. After this, an internal face model is adjusted in position, size, and scale in order to match the respondent's actual face. You can imagine this like an invisible virtual mesh that is put onto the face of the respondent: Whenever the respondent's face moves or changes expressions, the face model adapts and follows instantaneously. As the name indicates, the face model is a simplified version of the respondent's actual face. It has much less details, (so-called **features**) compared to the actual face, however it contains exactly those face features to get the job done. Exemplary features are single landmark points (eyebrow corners, mouth corners, nose tip) as well as feature groups (the entire mouth, the entire arch of the eyebrows etc.), reflecting the entire "Gestalt" of an emotionally indicative face area.



3 Feature classification

Once the simplified face model is available, position and orientation information of all the key features is fed as input into classification algorithms which translate the features into Action Unit codes, emotional states, and other affective metrics.

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Facial expression engines differ by the available metrics that are automatically coded:

Emotient FACET

- Head orientation (yaw, pitch, roll)
- 6 facial landmarks (ADD eye and nose position)
- 7 basic emotions, valence; complex states: frustration, confusion
- 20 Action Units
- respondent's sex and whether or not respondent wears glasses

Affectiva AFFDEX

- Head orientation (yaw, pitch, roll)
- Interocular distance and 34 facial landmarks
- 7 basic emotions; valence, engagement, attention
- 14 facial expression metrics (similar to Action Units)

Noldus FaceReader

- Head orientation (yaw, pitch, roll)
- 6 basic emotions; contempt (experimental), arousal, valence
- 20 Action Units

Here's a little theory (and analysis) behind it.

The translation from face features into metrics is accomplished **statistically**, comparing the actual appearance of the face and the configuration of the features numerically with the normative databases provided by the facial expression engines.

What does that mean? The current facial expression of a respondent is not compared one-by-one with all hundreds of thousands of pictures in the database – this would be quite tedious and take forever. Instead, the databases contain statistics and normative distributions of all feature characteristics across respondents from multiple geographic regions and demographic profiles as well as stimulus categories and recording conditions. Every facial expression analysis engine uses a different database. This is one of the reasons why you might get slightly varying results when feeding the very same source material into different engines.

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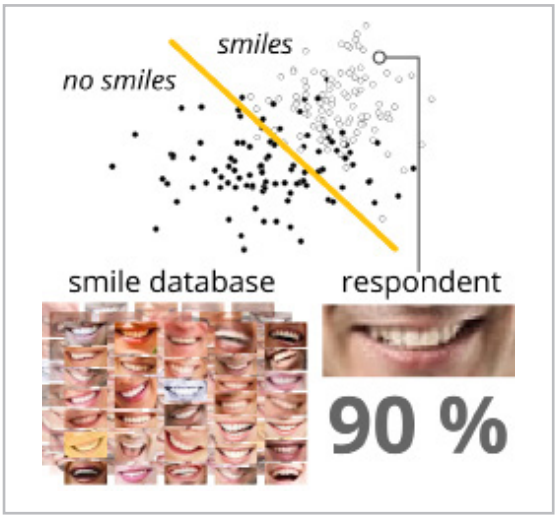
The classification is done on a purely **statistical level**. Here's an example: If the respondent's mouth corners are pulled upward, a human coder would code this as activity of AU12 ("lip corner puller") – stating that the respondent is smiling. The facial expression engine instead has to compute the vertical difference between mouth corners and mouth center, returning a value of 10 mm. This value is compared to all possible values in the database (values between 0 mm and 20 mm, for example).

In our example, the respondent's expression apparently is right in the middle of the "smile" distribution (0 < 10 < 20 mm). For the engine it's definitely safe to say that the current expression is stronger than a slight smile, however not as strong as a big smile.

In an ideal world, the classifier returns either "Yes" or "No" for each emotion, AU or metric. Unfortunately, it is not that easy. Take a look again at the "smile" classifier:



The filled dots (rather to the left) are all mouth configurations in the database that are not classified as smiles, while the white dots (rather towards the right) represent mouth configurations that are regarded as smiles.

The orange line denotes the classification criterion.

Everything on the left side of the line is classified as "not a smile", whereas everything on the right side is classified as "smile".

There obviously is a diffuse transition zone between non-smiles and smiles where some mouth configurations are misclassified – they might be subtle smiles that stay under the radar or other mouth opening configurations that might be rather yawns than smiles. As a consequence, the classifier can only return a **probabilistic result**, reflecting the likelihood or chance that the expression is an authentic "smile".

In our example, the respondent's smile is rather obvious, ending up all to the right side of the "feature space". Here, the classifier is very certain about the result of a smile and returns a solid 90%. In other cases, the classifier might be less confident about its performance.

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Feature classification is done for each emotion, Action Unit, and key feature independently - the classifier for smiles doesn't know anything about the classifier for frowns, they are simply coded independent of each other. The good thing about this is that the automatic coding is accomplished much more objectively than manual coding where humans – particularly novice coders – tend to interpret the activation of an Action Unit in concert with other Action Units, which significantly alters the results.

Before we dig deeper into the visualization and analysis of the facial classification results, we will have a peak into some guidelines and recommendations on how to collect best-in-class data.

Here we go.

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Equipment

Let's get practical.

What should you consider when acquiring high-quality data, what are optimal stimuli, what to keep in mind when recruiting and instructing respondents? We're here to help.

1 For starters, automatic facial expression analysis can be accomplished **online**, that is, while respondents are exposed to emotional stimuli and their facial expressions are monitored (and/or recorded).

2 Apart from online data collection, facial expression analysis can be applied **offline**, for example to process facial captures that have been recorded before. You can even record a larger audience and, with minimal editing, analyze each respondents' facial expressions.

For online automatic facial coding with webcams, keep the following camera specifications in mind:

1 **Lens:** Use a stadard lens; avoid wide-angle or fisheye lenses as they may distort the image and cause errors in processing.

2 **Resolution:** The minimum resolution varies across facial expression analysis engines. You certainly don't need HD or 4K camera resolutions - automated facial expression analysis already works for low resolutions as long as the respondent's face is clearly visible.

3 **Framerate:** The camera should have a stable framerate of 10 fps or higher. However, you can certainly process video feeds with 60 fps or more.

4 **Autofocus:** You certainly want to use a camera that is able to track respondents' faces within a certain range of distance. Some camera models offer additional, software-based tracking procedures to make sure your respondents don't get out of focus.

3 **Aperture, brightness and white balance:** Generally, most cameras are able to automatically adjust to lighting conditions. However, in case of backlighting the gain control in many cameras reduces image contrast in the foreground, which may deteriorate performance.

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A word on webcams: We suggest to use the *Logitech HD Pro webcam C920*. This camera is most suitable as it offers stable framerates, auto-focus, and allows access to aperture, brightness, and white balance settings.

You can of course accomplish automatic facial expression analysis with any other camera including smartphone cameras, IP cameras or internal laptop webcams (dependent on your application). However, be aware that these cameras generally come with limited auto-focus, brightness, and white balance compensation capabilities.

...did you know?

Some cameras might dynamically adjust the frame number dependent on lighting conditions (they reduce the frame rate to compensate for poor lighting, for example), leaving you with a video file with a variable frame rate. This certainly is not ideal as you will end up with variable frames per second, making it harder to compare and aggregate the results across respondents.

Offline automatic facial coding can be applied to pretty much any video material. Here's what you should keep in mind:

1 **Resolution:** The resolution of the video should be at least 640 x 480 pixels. Again, the determining factor is the size of the face in the recording.

2 **Frame rate:** A frame rate of 10 fps or higher is recommended.

3 **Video codec:** The rule of thumb? If the file can be played with Windows Media Player, chances are you can process it with automatic facial expression analysis. MP4 and WMV codecs are certainly supported. If your video is rendered in a non-supported codec, you can use freely available converter tools such as *Handbrake* or *AnyVideo Converter Free* to change the video codec. If you are not sure about the video codec, you can use *GSpot* (www.headbands.com). However, these video libraries can differ in how they read the codecs, resulting in slightly varying emotion data. If you process the same video decoded with two different libraries, this may result in two slightly different sets of emotion values.

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Respondent instruction

Setting up the environment for automatic facial tracking and expression analysis under controlled laboratory settings really is no rocket science. In actual fact, there are only a few things to consider before you can get going with your study.

1 Camera placement and respondent positioning

- Place the camera at the respondent's eye level (approximately) such that it faces the respondent directly. Face angles of ±20 degrees are acceptable, however automatic facial expression analysis delivers best results if the face is roughly center and frontal in the frame.
- For screen-based stimuli (videos, pictures, websites, games, software interfaces), attach the camera either above or below the screen. If respondents are supposed to use a keyboard, chances are they look down frequently. In this case, the face detector will report missing data. To prevent this, place the camera below the monitor.
- Make sure that faces fulfil the required minimum size. Facial analysis engines recommend minimal distances from ear-to-ear for optimal encoding of emotions, attributes, demographics, pose or Action Unit coding.
- Respondents should be seated comfortably to guarantee they will stay within the frame and in focus for the entire recording. Take into account that respondents change position once in a while.

2 Illumination

- Face tracking and facial expression analysis operate best with indoor, uniform, diffuse illumination. Accomplish a setup with standard contrast.
- Use indirect light (ambient lighting) as it illuminates the face evenly. Professional setups often use a softbox diffuser to accomodate for optimal lighting conditions.
- Avoid dim lighting. Facial expression analysis doesn't work in the dark.
- Avoid strong lights in the background (from a window or an artificial light source behind the respondent's head for example). Also, strong directional lighting shining on one side of the head (direct sunlight with strong shadows, for example) causes high contrast, potentially leading to issues in the facial expression analysis.

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3

Visibility of the face

- Facial expression analysis requires the visibility of emotionally sensitive facial landmarks such as eyebrows, eyes, nose, and mouth. If any of these are occluded, the face tracking and expression analysis may lead to only partial results.
- Tell respondents to not wear overly large, horn-rimmed glasses covering the eyebrows. Also, sunglasses will interfere with proper face capture.
- Long, unruly beards that occlude the mouth are not optimal (well-groomed three-day stubble should be fine, though).
- Facial jewelry, multiple mouth and eyebrow piercings can have a negative impact.
- Avoid hats, caps, beanies, etc. as they are likely to cast shadows and occlude facial landmarks. Equivalently, hair styling that partially covers the face (side-swept bangs, for example) should be excluded.
- Instruct respondents to not occlude their faces with or rest their heads on their hands.

What about talking, eating, drinking?

Talking, eating, and drinking all involve movement of the lower facial muscles, particularly in the area around the mouth and cheeks. While these activities will most likely not have any impact on face tracking, they certainly cause changes in facial expressions. As respondents talk, automatic expression coding procedures might incorrectly classify the muscular activations as indicator for the presence of certain emotions.

At the moment, this misclassification cannot be avoided, and unfortunately there is no procedure which could correct or exclude these time intervals in a video. However, you can mark those data portions where respondents talk, eat or drink in order to exclude them from the data analysis.

The gist of it? Advise your respondents to drink and eat sufficiently before the experiment. Chewing gum is an absolute no-go for facial expression analysis.

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Stimulus setup

In order to evaluate the individual facial expression characteristics of your respondents, some facial expression analysis engines require the collection of a “neutral” face expression during a baseline period, which ideally is around 5 to 10 seconds long and placed at the beginning of the actual data collection.

Running a baseline

In case baselining is required, you can run the following procedures:

1

Neutral baseline

In this condition, no stimuli are presented. Respondents are just sitting in a comfortable, relaxed position and look “neutrally” towards the camera. The recorded data reflects the respondent’s individual baseline expression in presence of neutral stimuli.

2

Baseline with variable stimuli

This condition contains stimuli with varying emotional content (a video with scenes that elicit neutral, positive, and negative emotions, for example). The variable baseline is considered to max out a respondent’s facial expressions, comprising the full spectrum of neutral expressions and expressions with high positive and negative valence. Our suggestion: Show a static, gray slide interrupted by scenes that trigger strong facial expressions.

Setting up stimuli

Once the baseline has been collected, you are certainly ready to start a recording in the desired test environment with the right respondents containing the stimulus set of interest.

...did you know?

Keep recording conditions clean and structured: Present functional stimuli long enough and use intermediate stimuli so that the facial expressions for all respondents can cool off and start from baseline levels for the next stimulus.

How should stimuli be presented? Facial expressions are very responsive and occur within tens to hundreds of milliseconds after stimulus onset. As a consequence, present any material long enough for respondents to process its content. This holds true for all sensory modalities: vision, hearing, taste, smell, and touch. Further, it might be useful to place cool-off stimuli of appropriate duration between the stimuli of interest in order to allow facial expressions to return to the neutral baseline state.

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Pictures, pictures, pictures

The International Affective Picture System (IAPS) is a database that has been specifically designed for emotion and attention research, comprising about 1,000 standardized color photographs that have been rated based on their emotional content. The IAPS is being widely used in several fields of academic and commercial research. Access to the database is restricted and requires signing an official request:

http://csea.phhp.ufl.edu/media/requestform.html

Quick recap

What do we know so far? We talked about the technology of facial coding, recommended equipment, respondent instruction, and stimulus setup. That's already quite some information to work with.

You snooze, you lose. Let's move one step further and sneak a peek beneath the surface of theory to get an even bigger grasp of automatic facial expression analysis: What can facial epression data *tell*?

In case you were wondering all along, be excited - we're about to find out.

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Data output & visualization

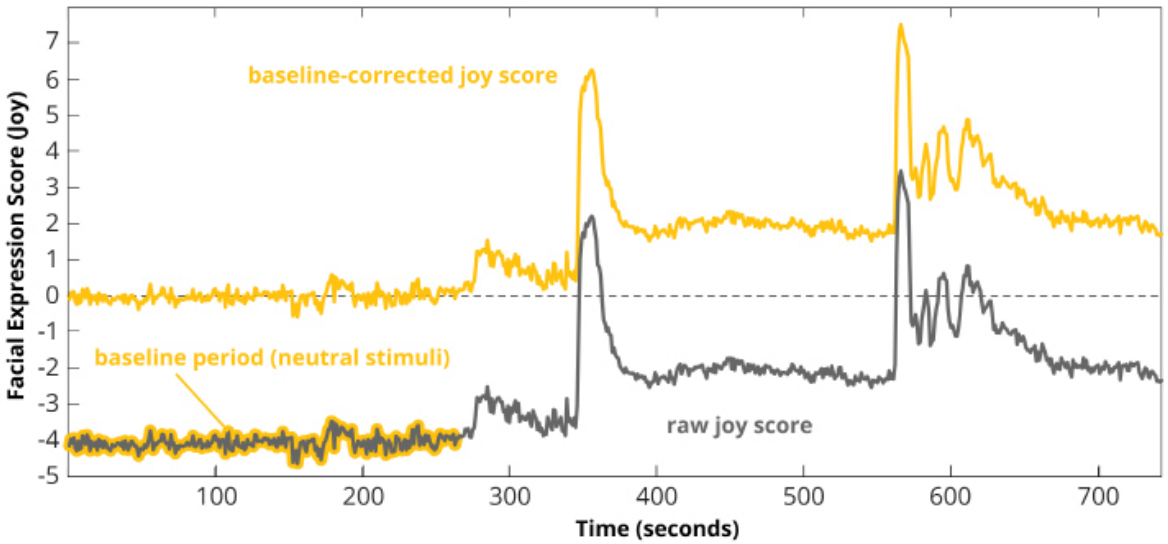
Automatic facial expression analysis returns **numeric scores** for facial expressions, Action Units, and emotions along with the degree of confidence. Most generally, you can think of these metrics as detectors: As the facial expression or emotion occurs and/or intensifies, the confidence score rises from 0 (no expression) to 100 (expression fully present).

The numerical values representing the facial expression can be plotted and visualized for both static images and videos (frame by frame time-course of emotion scores):

Take a look at the image. You might wonder why the facial expression is not classified as a single emotion - instead, it returns the three emotions joy (99%), surprise (10%), and disgust (2%). The other emotions returned values of 0%. How come?

Obviously, the current facial expression is a mixture of the three basic emotions. According to the classification, the expression most likely represents a highly joyful face with a slight indication for surprise.

Now that we covered static images, let's have a closer look into the time course of emotional data. For this purpose, we analyzed the facial expressions of respondents watching a 4 minute trailer with scenes of varying emotional arousal.



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Plotting raw scores vs. baseline-corrected scores

1

Raw score

First, you can analyze the raw expression scores, which represents the classification results of the facial expression engine for a certain respondent compared to the facial expressions stored in the global database. The benefit of this procedure is that the respondent's data can be compared directly with the expressions of thousands of other participants, giving you straightforward insights into emotional reactions. This procedure is recommended whenever you would like to aggregate data of several respondents, compare the data of two or more groups of respondents, or collate two or more stimuli (different versions of an advertisement, for example).

2

Baseline-corrected scores (if applicable)

Respondents differ in their "neutral" expression (baseline), and in some scenarios it makes sense to first baseline-correct the raw values in order to generate facial coding scores that reflect the relative expressions of a respondent independent of the database. Here's an example: Let's assume a respondent has a rather joyful baseline expression. If this individual baseline is not considered and raw scores are used, the amount of smiling and other joyful expressions within a certain time period will be misestimated.

To avoid this, do the following within each emotion:

1. Compute the median across all samples during the baseline period.
2. Subtract the median from all other samples.

...did you know?

Baseline-correcting values is recommended whenever you are interested in facial expressions of individual respondents, for example when evaluating training progress in a facial muscle training, which is supposed to be adaptive to the patient's individual base expression levels.

By baseline-correcting the respondent's data, the signal is shifted up- or downwards, allowing you to see those periods in time where the respondent shows changes in emotional expressions relative to their own baseline/neutral expression.

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A word on thresholding

Another important aspect for the analysis of facial expression data is whether to focus on actual scores or on thresholded data.

You can apply thresholds both in time and amplitude:

1

Thresholding in time
This thresholding technique defines a minimum duration in which a certain facial expression has to be active in order to be considered for further analysis. Temporal thresholding masks off short occurrences of facial expressions, no matter how strong they are.

If you're interested in longer-lasting emotional expressions, however not so much in quick facial expression "bursts", thresholding in time (using a time interval of 0.5 seconds, for example) might be a good solution for you. This means that any occurrence that is shorter than the defined window is disregarded.

...did you know?

Thresholding is a technique where you define a cut-off criterion – a threshold value – to highlight only the strongest or longest facial expressions while at the same time masking off the smaller, more subtle (and shorter) expressions.

2

Amplitude-based thresholding
Thresholding based on amplitutes specifies a minimum amplitude in which a certain facial expression has to be active in order to be considered for further analysis. Amplitude-based thresholding masks off low-amplitude occurrences such as a slight smile or a subtle furrow, no matter how long they are present.

If you're interested in stronger, rather obvious emotional expressions, however not too much into low-amplitude facial activity, we recommend amplitude-based thresholding.

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Particularly when thresholding based on amplitude, you can set either an absolute or relative cut-off. What exactly is the difference between those two cut-offs?

1 **Absolute thresholds**
Let's assume your facial expression data ranges on a scale from 0 (completely absent) to 100 (strongly present). You could set an absolute (hard-coded) threshold at a value of 50. In this case, all values above the threshold "survive", whereas all other values are set to zero. Absolute thresholding certainly is a good choice if respondents show high-amplitude expressions above the threshold, and if the respondent group is very consistent in their neutral baseline expression.

2 **Relative thresholds**
To identify the strongest facial expressions of a respondent irrespective of their absolute score, you have to define a relative threshold. Relative thresholds are set dependent on the data distribution of a respondent. Here's how it could work: You sort all scores according to their value and define a relative cut-off criterion at the 80th percentile, for example. This is the value which separates the lower 80% from the upper 20% of the data. With relative thresholding you can identify those moments in time where respondents showed their strongest facial expression (the top 20%, for example). Be aware that a relative threshold typically has different numerical values across respondents since the raw expression scores of each respondent differ (while the 80th percentile for respondent A might be at a value of 55, the 80th percentile for respondent B might be at a value of 20).

Agony of choice - which threshold should you use?

Which thresholds to use or to combine varies quite a lot dependent on the application. In any case, avoid setting thresholds arbitrarily. Instead, check existing papers and studies using the same stimulus material, a comparable participant pool, and/or the same set of facial expressions or Action Units.

Searching for papers on Google Scholar (scholar.google.com) is a first start: Just enter the facial expression analysis technique or engine in combination with the desired keywords – you will be surprised how many studies on specific facial expressions already have been conducted, serving as source of inspiration (and as necessary backup for the methodical description of the parameters in your report or paper). Definitely give it a try!

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Aggregation of facial data – raw or thresholded?

The aggregation of facial expression data across respondents can be accomplished based on the actual values, but also on the thresholded and binarized signal of each and every respondent. Here's how - step by step:

1. Break the continuous data of each respondent during the selected stimulus period into intervals with a certain window length (500 milliseconds, for example).

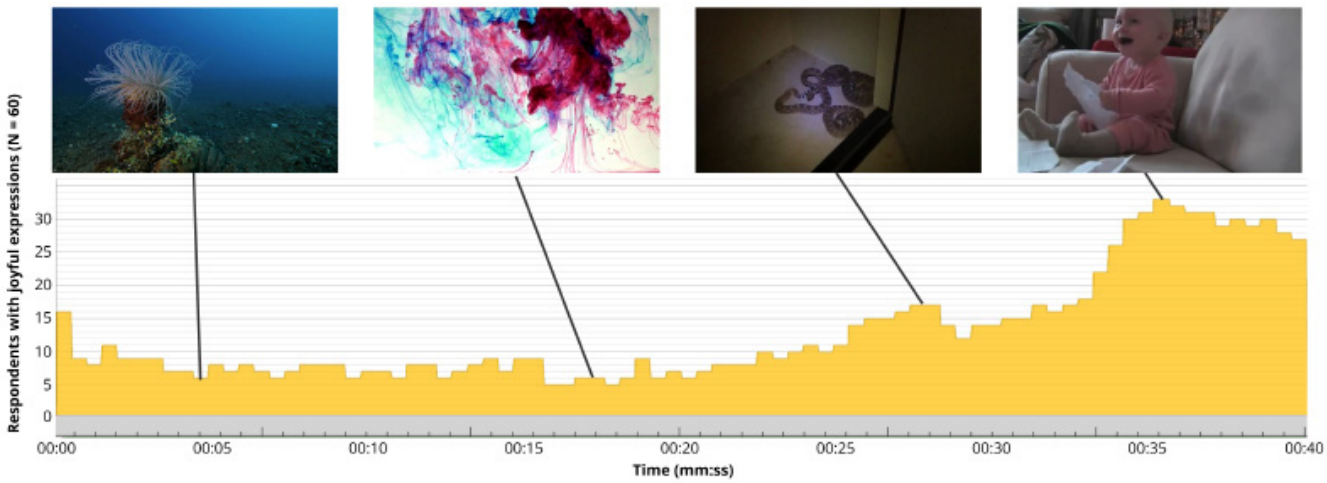
2. Compute the median of the facial expression score within each window.

3. If the median exceeds the threshold, assign a value of 1 („true"). Assign a value of 0 („false") to intervals where the data doesn't exceed the threshold. Instead of the actual facial expression scores, the binary values 0 or 1 are used.

4. In each time interval, sum up the binary scores across all respondents. Here's an example: In case you collected facial expression data from 10 respondents and all of them showed a facial expression above the threshold in a certain interval, the aggregated value for this interval is 10. If none of your respondents had a facial expression that exceeded the threshold, the aggregated value for this interval is 0.

The resulting curve is a visualization of the consistency of your respondents' facial expressions triggered by the provided stimulus material. The aggregated result relates directly to the physiological and psychological arousal of the audience.

You can now easily extract the number of occurrences of a specific facial expression, both within a single respondent as well as across all respondents. How? Just count!



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IMOTIONS®
BIOMETRIC RESEARCH PLATFORM

Facial expression analysis ... reloaded

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Adding biometric sensors

While facial recognition delivers valuable information on the quality of an emotional response, generally referred to as its **valence**, one core limitation of computer-based facial coding lies in its inability to assess someone's emotional **arousal**, that is, the intensity of an emotion.

You might ask why this is the case – doesn't a bright smile say it all? Doesn't it represent an evident indicator for a highly arousing feeling of happiness?

The truth is both yes and no. While it might very well apply for the emotional assessment of a single person, it definitely becomes more complex when comparing emotional expressions across different stimuli, respondents or groups.

...did you know?

The dynamics of facial muscle activity change across the day, the life cycle, and certainly across cultures. In addition there surely are strong individual differences in emotional expressions. Imagine watching a horror movie with your dad - while you are frightened to the core, he probably just keeps a straight face (although he might be as terrified by the film as you are).

If you aim to portray the emotional engagement of a larger audience or consumer group in response to emotionally loaded stimuli (ads, shows, pictures, videos) in its full complexity, it is essential to assess both the valence of the emotional expression and the associated arousal.

That's exactly where the tremendous value of multimodal research comes in.

Here's a list of the most widely used biomarkers for emotional arousal.

Eye tracking

Like no other experimental method, eye tracking offers incredible insights into visual attention. While eye tracking is commonly used to monitor where we direct our eye movements at a certain point in time, it also tracks the dilation of the pupil.

Changes in pupil dilation happen whenever the brightness of the stimulus material changes – when we step out of bright sunlight into a dark room, the pupils dilate to let in more light. The identical dilation effect occurs when we encounter stressful situations or when we're exposed to arousing stimuli or thoughts – the amount of dilation is proportional to the strength of arousal.

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As pupil dilation is an autonomic process, it cannot be controlled consciously. Exactly this circumstance renders the tracking of pupil dilation an excellent method to assess immediate emotional arousal.

GSR/EDA

Electrodermal activity (EDA), also referred to as galvanic skin response (GSR), reflects the amount of sweat secretion from sweat glands in our skin. Increased sweating results in higher skin conductivity. When exposed to emotional stimulation, we “sweat emotionally” – particularly on forehead, hands, and feet.

Just as pupil dilation, skin conductance is controlled subconsciously, therefore offering tremendous insights into the unfiltered, unbiased emotional arousal of a person. GSR measurements can be done with lightweight and mobile sensors, which makes data acquisition very easy.

In addition, automatic data analysis procedures extract key metrics on the fly, giving you immediate access to the underlying changes in emotional arousal.

EEG

Electroencephalography is a neuroimaging technique measuring electrical activity generated by the brain from the scalp surface using portable sensors and amplifier systems. It undoubtedly is your means of choice when it comes to assess brain activity associated with perception, cognitive behavior, and emotional processes.

Among all biosensors, EEG has the highest time resolution, thereby revealing substantial insights into sub-second brain dynamics of engagement, motivation, frustration, cognitive workload, and further metrics associated with stimulus processing, action preparation, and execution.

Simply put: EEG impressively tells which parts of the brain are active while we perform a task or are exposed to certain stimulus material.

Unlike facial recognition, EEG is able to monitor the global emotional state of a person, which cannot be controlled consciously - you can fake your smile, but you can’t trick your brain. Combining the two modalities allows you to get insights into both the moment-by-moment changes in emotional expression as well as variations in emotional states across a longer time span.

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EMG

Electromyographic sensors monitor the electric energy generated by bodily movements of the face, hands or fingers, etc. Use EMG to monitor muscular responses to any type of stimulus material to extract even subtle activation patterns associated with consciously controlled hand/finger movements (startle reflex). Also, facial EMG can be used to track smiles and frowns in order to infer one's emotional valence.

ECG/PPG

Track heart rate, or pulse, from ECG electrodes or optical sensors (PPG) to get insights into respondents' physical state, anxiety and stress levels (arousal), and how changes in physiological state relate to their actions and decisions.

Complementing facial expression analysis with eye tracking, GSR or EEG allows you to get insights into both the valence (quality) of an emotional response as well as the amount of arousal (intensity) it triggers in your respondents.

Collecting synchronized data from multiple modalities adds more to the picture as every sensor contributes a valuable aspect of emotional responses that you cannot get with any other. You might even uncover a previously unknown, entirely new effect in cognitive-emotional processing – just think about how your face would brighten up!

Biometric sensors in concert...

Each sensor reveals a specific aspect of human cognition, emotion, and behavior. Depending on your individual research question, consider to combine facial expression analysis with two or more additional biosensors in order to gain meaningful insights into the intricate relationships between the autonomic regulation of emotional arousal and valence, cognition, attention, and motivation.

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Facial expression analysis done right with iMotions

Let's recap

While automatic facial expression detection itself is quite easy to do, the analysis and interpretation of the collected data is a bit trickier. Also, as facial expressions only monitor the valence of a response, we recommend to combine facial expressions with other biosensors in order to get the "bigger picture" on how arousal and valence, motivation and emotion interact in response to physical or psychological stimuli.

Before you can kick off your facial expression research, you definitely need to think about which recording and data analysis software to use. Usually, separate software is required for data acquisition and data processing. Although some manufacturers offer integrated solutions, you will most likely have to export the raw data to a dedicated analysis software for data inspection and further processing.

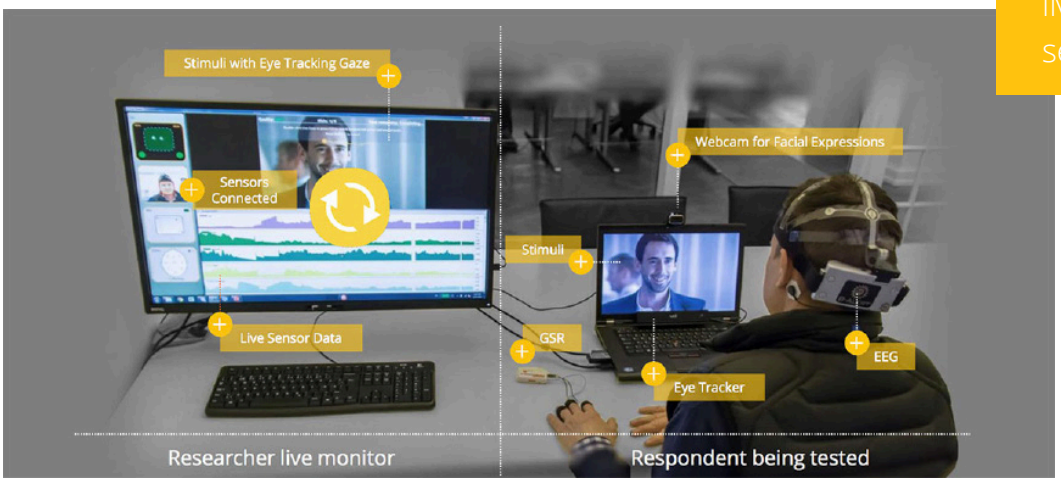
Which multimodal software solution is the one you need to integrate any type of stimulus with eye tracking and other biometric sensors without having to piece everything together?

iMotions Biometric Research Platform

IMOTIONS
BIOMETRIC RESEARCH PLATFORM

iMotions Biometric Research Platform is one easy-to-use software solution for study design, multisensor calibration, data collection, and analysis.

Out of the box, iMotions supports over 50 leading biometric sensors including facial expression analysis, GSR, eye tracking, EEG, and ECG/EMG along with survey technologies for multimodal human behavior research.



iMotions multi-modal sensor setup

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What's in it for you?

Get the most from facial expression analysis. From start to finish, iMotions got you covered:

1. Run your multimodal study on **one single computer.**
2. Forget about complex setups: iMotions requires **minimal technical skills** and effort for **easy experimental setup** and data acquisition.
3. Get **real-time feedback** on calibration quality for highest measurement accuracy.
4. Draw on unlimited resources: **Plug & play any biometric sensor** and **synchronize it with any type of stimulus**.
5. Receive **immediate feedback on data quality** throughout the recording across respondents.
6. Worried about data synchronization? Don't be. While you can work on what really matters, **iMotions takes care of the synchronization of data streams across all sensors**.

iMotions introduces innovative aggregation of individually coded facial expression data

1. You can use this innovative facial expression aggregation procedure to get **insights into the consistency of facial expressions** elicited by the provided stimulus material as well as the underlying valence of the response.
2. Working with time windows, iMotions can **pool together significant occurrences of facial expressions** that are happening approximately at the same time.
3. iMotions can **count the number of respondents that showed a response** (happy, sad, angry etc.) in a certain time window. The aggregated result relates directly to the audience.

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Further reading

Here are our recommended reads to dig deeper into facial expression analysis:

1 Adolphs, R. (2002). Neural systems for recognizing emotion“. Current Opinion in Neurobiology 12 (2): 169–177.

2 Fox, E. (2008). Emotion Science: An Integration of Cognitive and Neuroscientific Approaches. Palgrave MacMillan.

3 Kodra, E., Senechal, T., McDuff, D., el Kaliouby, R. (2014). From Dials to Facial Coding: Automated Detection of Spontaneous Facial Expressions for Media Research. http://www.affectiva.com/wp-content/uploads/2014/09/From_Dials_to_Facial_Coding_Automated_Detection_of_Spontaneous_Facial_Expressions_fo.pdf

4 Littlewort, G., Whitehill, J., Wu, T., Fasel, I., Frank, M., Movellan, J., & Bartlett, M. (2011). The computer expression recognition toolbox (CERT). In Face and Gesture 2011 (pp. 298–305).

5 Matsumoto, D. (2001). Culture and Emotion. In D. Matsumoto (Ed.), The Handbook of Culture and Psychology (pp. 171-194). New York: Oxford University Press.

6 Müri, R. M. (2015). Cortical control of facial expression. Journal of Comparative Neurology. Accepted article, ePub ahead of print.

7 Rinn, W. E. (1991). Neuropsychology of facial expression. In R. Feldman & B. Rime (Eds.), Fundamentals of nonverbal behavior (pp. 370). New York: Cambridge University Press.

8 Viola, P., Jones, M. (2004). Robust Real-Time Face Detection. International Journal of Computer Vision, 57, 137–154.

Ready to elevate your research?

Learn how to launch your facial expression study at full speed at www.imotions.com

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