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Algebraic integration models of facial features of expression: A case made for pain

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Study of facial behaviour received a strong impulse from the upsurge of dependable measurement systems of the face in the late seventies (Ekman & Friesen, 1981; Rosenberg, 1997). Among these, the *Facial Action Coding System* - FACS (Ekman & Friesen, 1978) quickly imposed itself as the golden standard of facial measurement, over competitors such as MAX (Izard, 1979) or FACEM (Katsikitis & Pilowsky, 1988). This privilege ensued from the option to code for the entire repertoire of minimal anatomically-based movements observable in the face, designated as Action Units (AUs), rather than for facial gestalts. The following advantages were thereby ensured: (1) comprehensive coding of the full range of facial behaviour, instead of just particular samples of it; (2) a clear-cut, tidy separation between description and inference. Altogether, these features render FACS compatible with any theoretical framework regarding facial expression, and allow for the translation of any alternative coding system into the universal vocabulary of AUs.

At the level of measurement, FACS is entirely descriptive. However, the final purpose of its use is inferential, aimed at identifying expressions of underlying states (e.g., pain, emotion, deceptive intent) which are typically composed of several AUs. A vast body of evidence is available on the occurrence of particular AUs with an array of expressions, chiefly of emotion (Ekman, Irwin, Rosenberg, & Hager, 1995). In contrast, little is known on how AUs integrate into a facial display and what each contributes, as an informer, to its expressive power. This signals an age-old limitation in the study of decoder's processing of expressions, focused for the most part on recognition accuracy and incapable of highlighting the processes by which observers extract and combine expressive information from the face (Walbott & Ricci-Bitti, 1993).

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Research with FACS followed two directions: (1) measurement of spontaneous facial behaviour, in which the face is viewed as a *dependent variable*; (2) the study of facial expressions recognition, in which the face is taken as an *independent variable*, affecting the behaviour of observers/decoders (Rosenberg, 1997). The first path was hampered by the time-intensive nature of observational measurement, and awaits the promise of automated coding (Bartlett et al., 2006). The second one was considerably more exploited, but suffers from severe lack of stimuli enabling manipulations at the analytical level required by AUs (Hager, 1997; Pittinger, 1991; Wherle, Kaiser, Schmidt, & Scherer, 2000). An increasingly advocated solution has been the use of facial modelling, resting on major advances in 3-D realistic facial expression synthesis (Terzopoulos & Waters, 1990). A convincing illustration of this strategy was given by Spencer-Smith et al. (2001), who carefully implemented and calibrated 16 FACS defined AUs in the modelling environment of Poser 4.

The present study similarly uses synthesized expressions as stimuli. However, this is simply seen as a first step to the experimental analysis of expression processing. A second seeming condition is to be capable of adequately handling multidetermination of facial expressions. According to integration information theory (IIT), this means ascertaining, first, the existence of an integration rule, and second, as a benefit of the rule, disintegrating the composite effect into the separate contributions of the various determinants (Anderson, 1981, 1982, 1996). Lack of suitable theory and method can be seen in the difficulties of previous attempts to study AUs interplay. The use by Walbott and Ricci-Bitti (1993) of the "relative shift measure" to assess the relative importance of separate AUs in a combination illustrates one such case. As demonstrated by Anderson, this index has a variable meaning depending on the specific integration rule that applies (Anderson, 1982, pp. 276-277). Efforts at weighting separate AUs contributions through correlational analysis, as illustrated by Prkachin (1997), run into similar if not bigger troubles (Anderson, 1982, p. 271).

This study seeks to outline the advantages of conjoining synthetic modelling of AUs with IIT methodology, as a basis for a truly functional, as opposed to taxonomic, approach to facial expression processing. The general strategy is illustrated by taking synthesised AUs as factors, with intensity degrees as levels, in typical integration tasks requiring an overall integrative judgment. Two classical objections to "decoding" studies are at once discarded by the procedure. Reliance on continuous response methodology evades the methodological pitfalls pointed out to "alternative-choice" formats (Russel, 1994). The other objection is conceptual, that "decoding" presupposes an "encoding" (Russel et al., 2003): since it is the functional integration of AUs and not recognition accuracy that actually comes under scrutiny, any rules found will rightfully express the working knowledge of the “decoder”, whatever the encoding process may be. These are direct benefits of a functional approach.

Pain expressions are used in the following as a case study. Being an empirical, inductive theory, any intended application of IIT must start by verifying the existence of integration rules in the concerned domain. A specific goal of this study is thus to show that cognitive algebra and functional measurement do have a grip over the integration of AUs into facial expressions of pain.

Method

Subjects

Four groups (G1 to G4) of undergraduate students at the universities of Coimbra and Aveiro participated in the study. Each group was assigned one of four variants of an experiment differing only by the stipulated response dimension: intensity task for G1 ($n = 36$), analgesia task for G2 ($n = 23$), mixed-analgesia task for G3 ($n = 22$), and naturalness task for G4 ($n = 35$). All subjects had normal or corrected to normal vision and were unaware of the purpose of the study.

Stimuli

Stimuli consisted of a set of 3-D realistic synthetic faces depicting either specific AUs or AU combinations. All faces were modelled in Poser 6, according to FACS guidelines, and building on the geometry of a single male virtual character. Previous observational studies with FACS identified four facial actions as components of a “general expression” of pain (Prkachin, 1997; Solomon, Prkachin, & Farewell, 1997). Of these, three were targeted for modelling: *brow lowering* (AU 4), *orbit tightening* (AU 6&7) comprising “cheek raise” (AU 6) and “lid tightening” (AU 7), *levator contraction* (AU 9&10) including the effects of “nose wrinkling” (AU 9) and “upper lip raise” (AU 10). Because it implied a frequency measure, “eye closure” (AU 43) was left aside from the modelling. In the FACS classification, AU 4, AU 6, and AU 7 belong to the upper face while AU 9 and AU 10 correspond to up/down actions of the lower face.

Different intensity levels were implemented for each AU. FACS intensity scoring provides five bands of intensity, from “trace” to “maximum evidence”, together with threshold descriptive criteria to assign a correspond-

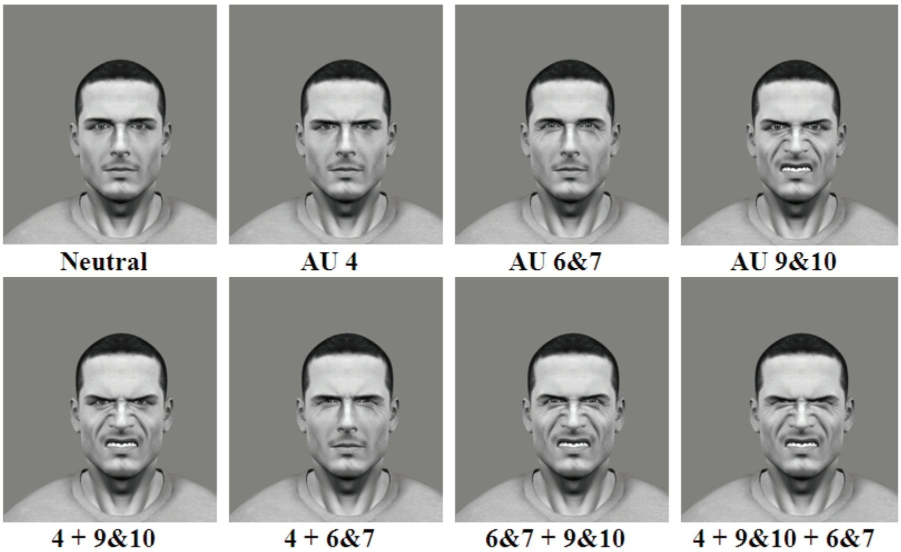


Figure 1. Synthesized faces used as stimuli. Upper row*:* baseline neutral face, followed by an illustration of each of the three AUs elected as factors at its maximum levels. Bottom row*:* two-way and three-way AU combinations, involving the highest intensity levels of the combined AUs.

ing score, from *A* to *E*. Intensities for AU 4 and AU 9&10 were chosen at the borders of "slight-marked", "pronounced-severe", and "extreme-maximum" (three levels). As for AU 6&7 (orbit tightening), four levels were obtained by first distinguishing a low ("slight-marked") and high ("extreme-maximum") level in each unit, and then combining them across units. Those options were meant to ensure fair coverage of the natural dynamic range of each factor and, additionally, to have the "molar" levels in one factor (orbit tightening) actually embedding a lower level, "molecular" subdesign [2 (AU 6) × 2 (AU 7)]. A further pain expression, somewhat more extreme than any of the others, was also modelled to be used as an end-anchor.

Design and procedure

All experiments obeyed a repeated measures 3 (brow lowering) × 3 (levator contraction) × 4 (orbit tightening) full factorial design with two replicates. Stimuli were randomly presented in the middle of a fontoparallel screen located 60 cm from the subject. On each trial, a baseline-neutral face appeared for 1 sec and was immediately followed by a face embodying a specific combination of factor levels. The effect obtained was a distinctive apparent movement going from neutral to a pain-conveying expression. Besides the main design, all two-way (3) and one-way (3) subdesigns were also represented in the set of stimuli-faces.

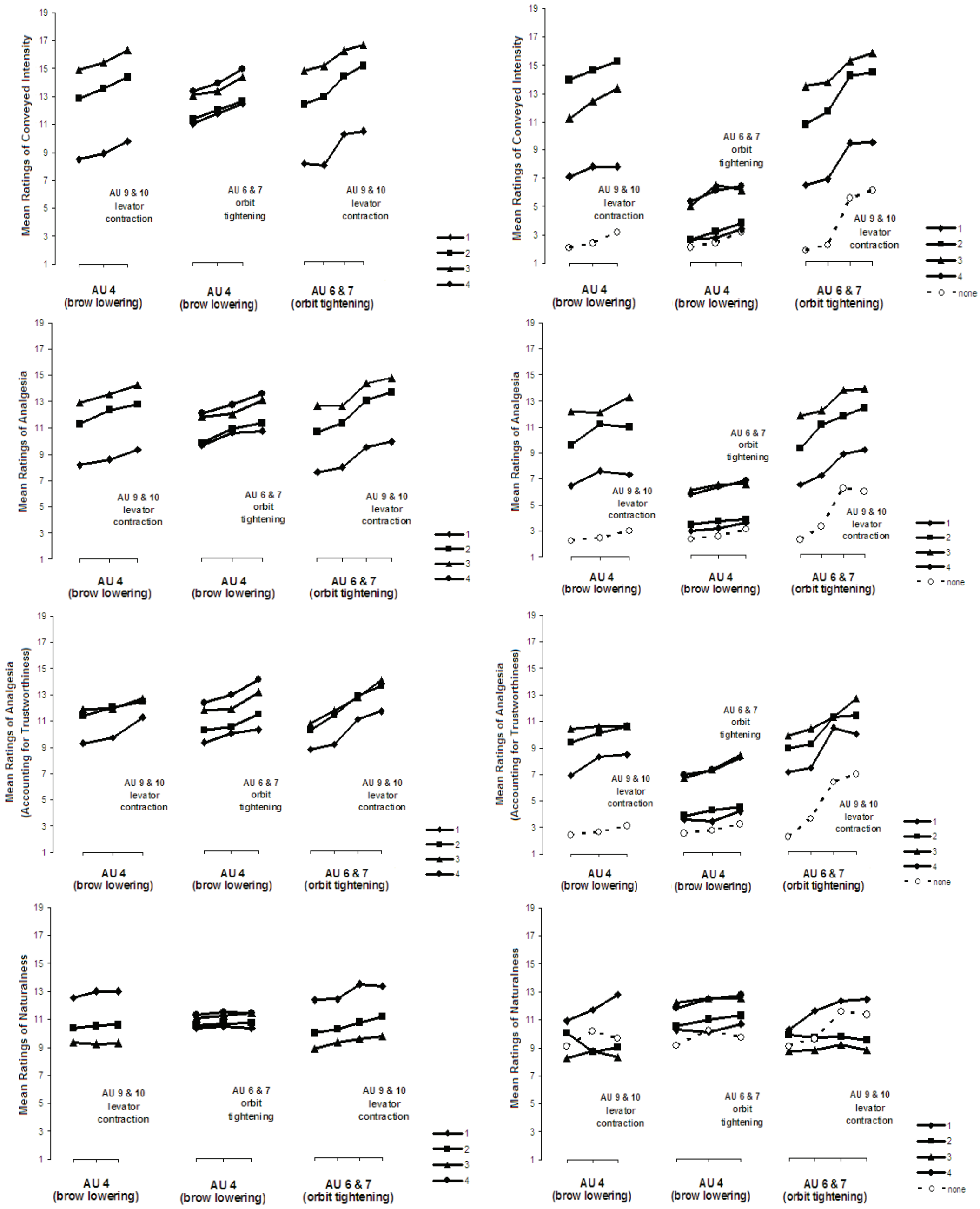
Subjects were run singly and went through a variable number of training trials before starting the regular experiment. Depending on the assigned task, they were made to judge either "expressed intensity", "naturalness of the pain expression", "dosage of analgesia required to stop pain", or "dosage of analgesia required, also accounting for the trustworthiness of the expression". The answer was always given on a 0-20 rating scale by inputting a value on a keyboard. In the "intensity" and "analgesia" tasks, the scale was end-anchored with the neutral face (for 0) and the "somewhat-more-extreme" face (for 20).

Results

Cognitive algebra

Figure 2 presents the results. Plots obtained for all pairs of factors in the three-way designs (ratings were averaged over the third factor) are displayed in the left column. Factorial diagrams in the right column represent the corresponding two-way subdesigns. Rows correspond to different tasks, from intensity (top) to naturalness (bottom). Visual inspection of the left column shows near-parallelism to be the general case. As an implication of the parallelism theorem (Anderson, 1981, 1982), this suggests an additive-type integration rule and at the same time supports linearity of the response scales. With the exception of naturalness (left bottom panel), where AU 4 (brow lowering) fails to induce an elevation of the curves, factors appear to contribute to the final response in all other tasks. This is confirmed by significant main effects obtained for all factors in every task ($p < 0.02$) except for AU 4 in the naturalness task ($p = 0.52$).

The practical statistical sign of parallelism is nonsignificant interaction between factors. This was the case in general. Two significant interactions were nevertheless found, the levator contraction × orbit tightening interaction in the intensity task ($p = 0.04$) and the brow lowering × levator contraction interaction in the mixed-analgesia task ($p = 0.02$). Additional independent support for additivity and scale linearity came from the 2 (AU 6) × 2


Mean Ratings of Conveyed Intensity
AU 9 & 10 levator contraction
AU 6 & 7 orbit tightening
AU 9 & 10 levator contraction
AU 4 (brow lowering)
AU 4 (brow lowering)
AU 6 & 7 (orbit tightening)
1
2
3
4
Mean Ratings of Conveyed Intensity
AU 9 & 10 levator contraction
AU 6 & 7 orbit tightening
AU 9 & 10 levator contraction
AU 4 (brow lowering)
AU 4 (brow lowering)
AU 6 & 7 (orbit tightening)
1
2
3
4
none
Mean Ratings of Analgesia
AU 9 & 10 levator contraction
AU 6 & 7 orbit tightening
AU 9 & 10 levator contraction
AU 4 (brow lowering)
AU 4 (brow lowering)
AU 6 & 7 (orbit tightening)
1
2
3
4
Mean Ratings of Analgesia
AU 9 & 10 levator contraction
AU 6 & 7 orbit tightening
AU 9 & 10 levator contraction
AU 4 (brow lowering)
AU 4 (brow lowering)
AU 6 & 7 (orbit tightening)
1
2
3
4
none
Mean Ratings of Analgesia (Accounting for Trustworthiness)
AU 9 & 10 levator contraction
AU 6 & 7 orbit tightening
AU 9 & 10 levator contraction
AU 4 (brow lowering)
AU 4 (brow lowering)
AU 6 & 7 (orbit tightening)
1
2
3
4
Mean Ratings of Analgesia (Accounting for Trustworthiness)
AU 9 & 10 levator contraction
AU 6 & 7 orbit tightening
AU 9 & 10 levator contraction
AU 4 (brow lowering)
AU 4 (brow lowering)
AU 6 & 7 (orbit tightening)
1
2
3
4
none
Mean Ratings of Naturalness
AU 9 & 10 levator contraction
AU 6 & 7 orbit tightening
AU 9 & 10 levator contraction
AU 4 (brow lowering)
AU 4 (brow lowering)
AU 6 & 7 (orbit tightening)
1
2
3
4
Mean Ratings of Naturalness
AU 9 & 10 levator contraction
AU 6 & 7 orbit tightening
AU 9 & 10 levator contraction
AU 4 (brow lowering)
AU 4 (brow lowering)
AU 6 & 7 (orbit tightening)
1
2
3
4
none

(AU 7) subdesign embedded in the four levels of the factor orbit tightening. When levels of this facial action were singly presented, the design satisfied all criteria for an additive model, in every task but the one of naturalness. Notably, the same also happened when analysis was based instead on the marginal means derived for AU 6&7 in combination with the other factors. Even if it is contingent on the valuation of levels of orbit tightening, this result affords cross-validation between the two implied additive operations, as well as a cross-check on response scale validity (Anderson, 1982, p. 113).

Regarding two-way subdesigns (right column panels), crude parallelism is also apparent, except for the naturalness task. Statistical analysis supports graphical parallelism. None of the interaction terms were significant in tasks other than naturalness, where both the AU 4 × AU 9&10 and AU 9&10 × AU 6&7 interactions achieved significance ($p = 0.03$ and 0 .02, respectively). Judging by the graphics, these interactions reflect a strong dominance effect of levator contraction, which only allows other AUs to function when represented at its lower level. Except for naturalness, the absence of crossovers produced by the dashed line favours an adding model over an averaging model with equal-weights.

Further evidence suggests that the same occurs in the main tasks. Curves in the two-way designs show no sign of steeper slopes (as they might, in the general additive case, if a third factor was averaging with one or two of the others). Also, no averaging model could be fitted satisfactorily to the three-way designs using the AVERAGE program. It is thus plausible to assume that subjects are chiefly adding the contributions of each facial action. This conclusion requires qualification from inspecting the operation of the factor levator contraction in the naturalness task, which induces a decrease in ratings as the AU levels increase. Although it is formally the same as adding, this pattern actually illustrates a subtraction rule.

Hierarchical cluster analysis performed on each design have shown this pattern to be due to a major cluster of subjects ($n = 24$, out of 35); the remaining subjects hold to an adding rule, but drastically limit the effects of the highest level of AU 9&10. Two similar clusters of subjects were found in the mixed-analgesia and analgesia tasks; the subtractive subgroups, however, were a minority (6 out of 22 subjects in the former, and 2 out of 23 in the later). No subgroups were found in the intensity task. This consistent re-

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Figure 2. Factorial patterns of results obtained from the main three-way designs (left column) and subdesigns (right column). Plots on the left represent averages over the third, absent factor. The two-way subdesigns presented on the right were added with mean ratings from one-way designs (dashed lines). Rows correspond to different integration tasks, differing solely by the judgement dimension.

duction in the number of subtractive subjects across tasks appears to be a function of decreased importance of reliability considerations. It suggests that shifting AU 9&10 to a subtractive mode is one of the ways subjects handle reliability issues. A second way is to reduce its adding effects: this was apparent in the second cluster of subjects in the naturalness task, and is also suggested by a consistent reduction in the range of levator contraction going from intensity, through analgesia, to mixed-analgesia tasks. Overall, an additive-type model looks warranted which, depending on the subjects, AUs, and tasks may include both adding and subtraction operations.

Functional measurement

Relative range indices. Unlike averaging, adding-subtracting models do not allow proper separation of weight and scale parameters. However, an overall index of importance is given by the "relative range" of factors (RRI) which can be used under three conditions: (1) range selection on the side of the stimuli must not be arbitrary, corresponding either to maximum range or to a natural, representative range of variation; (2) a linear model must apply; and (3) the response scale must be linear (see "relative range index" in Anderson, 1982). All these conditions are satisfied in the present case. The values found are presented in Table 1.

Tasks	RRI *9&10 / 4*	RRI *6&7 / 4*	RRI *9&10 / 6&7*
Intensity	5.91	2.01	3.04
Analgesia	6.19	2.67	2.25
Mixed-Analgesia	3.43	2.52	1.77
Naturalness (Cluster1)	7.59	2.77	3.33

Table 1. Mean relative range, RRI, of the effects of facial actions in all four tasks.

Diminished relative importance of levator contraction regarding other facial actions is observed in the mixed-analgesia task (third row: second and fourth column). This is also true of the analgesia task for levator contraction relative to orbit tightening. A declining trend in RRI can actually be seen in the last column, going from intensity to mixed-analgesia. Compared to the intensity task, orbit tightening shows increased importance over brow lowering in all other tasks.

Values for naturalness present the peculiarity that levator contraction is operating subtractively: therefore, higher importance of levator contraction means *stronger decrease* in response, while diminished importance found in the mixed-analgesia and analgesia tasks means *reduced increase* in response. In both cases, the action of AU 9&10 is being "discounted". Univariate between-subjects ANOVAs, followed by multiple comparisons, revealed a significant difference in relative importance of levator contraction between intensity and mixed-analgesia tasks ($p = 0.03$).

Functional scales of "gross" stimuli values. The finding of an adding model allows legitimate use of marginal means of the responses as functional values of the stimuli (Anderson, 1981, 1982). These are presented in Figure 3 (normalized to the functional range; conventional zero given by the lowest value). One point to be noticed is the almost perfect equivalence of the scales yielded by the intensity, analgesia, and naturalness tasks for the factor levator contraction. Given that levator contraction acted subtractively in the naturalness task, this indicates that the operation and not the value of informers had changed with the response dimension. A second notable point concerns the spacing of levels of orbit tightening (AU 6&7) across tasks. The two values at the bottom correspond, in the embedded 2 × 2 design, to the low level of AU 6 (cheek raise) combined with the low and high levels of AU 7 (lid tightening), respectively; the same happens with the functional values at the top, involving combinations of the high level of AU 6. Greater spacing between end-values and intermediate values in the mixed-analgesia task thus indicates a larger contribution of AU 7. This might suggest an attentional interpretation to the increased importance of orbit tightening in this task. Inversion of positioning of Levels 3 and 4 in the naturalness task suggests a shift from adding to subtraction at the high levels of intensity of orbit tightening. Finally, the distinctive functional scale of AU 4 in the naturalness task merely reflects the absence of effects of AU 4.

Conclusion

The results show that an additive rule governs the integration of pain-relevant AUs. Depending on the dimension under judgment and on the specific AU, additivity can take the form of either adding or subtracting. This change in operation affects mostly the levator contraction (AU 9&10), a ver-

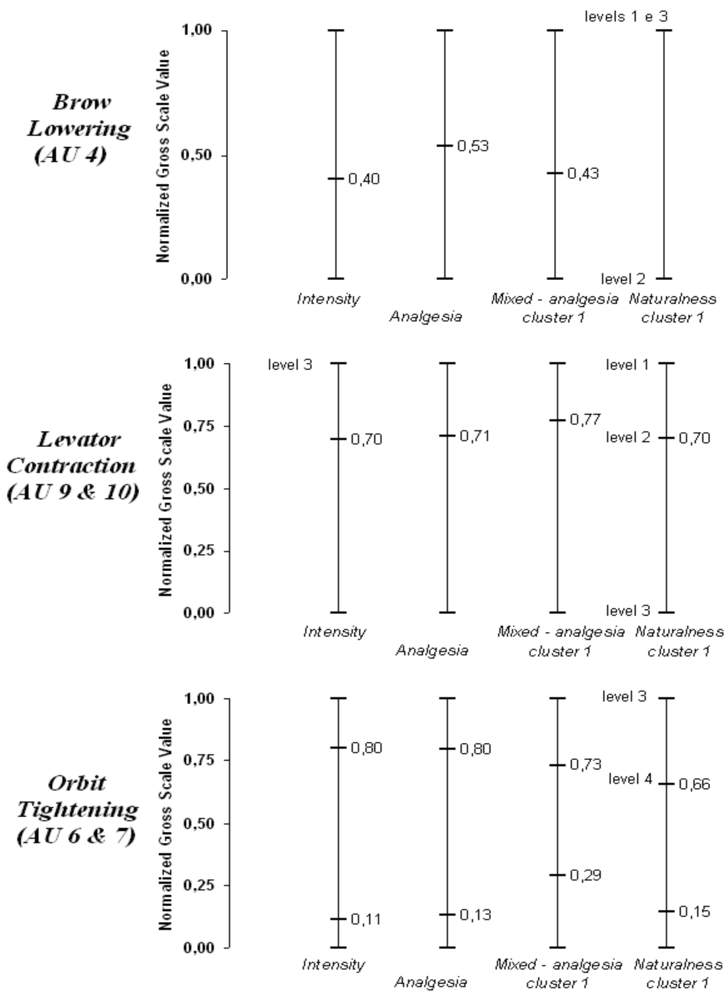

Figure 3. Gross functional scale values derived for the three pain-related AUs from the four integration tasks. Normalization to the functional range in each case was used to ensure easy comparison across tasks. Since two clusters of subjects were identified in the "naturalness" and "mixed-analgesia" tasks, data are based on the prevailing subgroup.

tical action of the lower face, which predominantly operates in a subtractive manner in the "naturalness task", and in an adding manner in the remaining tasks. A consistent inversion in the functioning of the two higher levels of orbit tightening (AU 6&7) also occurs in the naturalness task, which may be interpreted as a shift to a subtractive mode at very high intensities. This interpretation is strengthened by the finding of a cluster of subjects (n = 5) in which orbit tightening played a consistent subtractive role, with complete inversion of the ordering of levels. These outcomes can be put into relation with the often reported finding that both lay people and health professionals underestimate pain conveyed in the face at high levels of intensity (Craig, Hyde, & Patrick, 1997; Solomon et al., 1997). Decreasing "naturalness" may be one source of the problem.

Differently from averaging, summative-subtractive rules do not allow for distinguishing scale values and weight in the contribution of informers. However, since range selection for each AU was made in a way as to represent a natural gamut of variation, and since an additive model applied, quantitative indications on the relative importance of AUs could be obtained from the ratio of ranges among factors, taken two by two. An increase in relative importance of orbit tightening (higher face) regarding both levator contraction (lower face) and brow lowering (higher face) was found in the "analgesia" and "mixed-analgesia" tasks, compared to the intensity task. This kind of results can be instrumental to the issue of identifying cues upon which subjects rely when credibility issues are at stake.

Also, since marginal means provide estimates of "gross" scale values, functional scales of AUs, normalized to their respective range, were built for comparison across tasks. As a notable point, the subtractive levator contraction in the "naturalness task" yields an essentially equivalent scale to the ones of intensity and analgesia, when corrected for the inversion. This is an instance of cross-task scale invariance: regarding AU 9&10, the difference in response dimension thus seems to be determining a change in the operation rule (subtraction in the place of adding) rather than in the valuation of stimuli.

Many of the problems found in the literature on facial expressions, chiefly of emotion, are reminiscent of problems congenial to the IIT research program since its early stages: configurality and invariance, part-whole versus whole-part processing, contextual versus focal effects, issues of relative importance, order effects in serial patterns (see "basic experiments in IIT" in Anderson, 1981). It is thus reasonable to expect that they may find principled solutions in this rationale. By showing how synthetic modelling of AUs renders pain expressions accessible to cognitive algebra and functional measurement, outcomes of the study can be seen as generally supportive of a systematic attack to facial expression processing along these lines.

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Abstract

The upsurge of measurement systems of the face in the late seventies originated a flurry of studies of facial behaviour. The facial action coding system (FACS) has become the most widely used of these systems. Its comprehensive coding of all minimal visible changes of appearance in the face, the facial action units (AUs), allowed for a strict separation between description and inference. As a result, many AUs were descriptively documented to occur with certain expressions, namely of emotion and pain. However, the gap from description to inference can be seen from the virtual absence of knowledge on how AUs combine into meaningful expressions, and what each contributes to their expressive power. This study conjoins the modelling of AUs in 3-D realistic synthetic faces within the integration information theory framework allowing for truly manipulating AUs as independent variables and affording suitable theory and method to handle multi-determination. This approach is illustrated in the domain of pain expressions by taking three pain relevant AUs as factors in typical integration tasks. Outcomes reveal that an additive (summative and/or subtractive) rule governs most aspects of AUs integration, with a major contribution of up/down actions of the lower face. At a more general level, they support the advantages and prospects of a functional, as opposed to taxonomic approach to the processing of facial expressions.

Riassunto

L'aumento improvviso di sistemi di misurazione della faccia nei tardi anni settanta ha dato origine ad una raffica di studi del comportamento facciale. Il sistema di codificazione della azione facciale (FACS in inglese) è diventato il più usato di tali sistemi. La codificazione esauriente che esso fa di tutti i minimi cambiamenti visibili dell'aspetto della faccia, le unità di azione facciale (UA), ha permesso una separazione rigorosa tra descrizione e inferenza. Come risultato di ciò, venne documentato descrittivamente che molte UA si verificano con certe espressioni, in particolare di emozione e dolore. Tuttavia, si può vedere che c'è divario fra descrizione e inferenza dalla assenza virtuale di conoscenza circa come le UA si combinano in espressioni significative, e circa il contributo di ciascuna di esse al loro potere espressivo. Il presente studio unisce il modellamento di UA in facce sintetiche tridimensionali realistiche allo schema di riferimento della teoria della integrazione delle informazioni permettendo di manipolare veramente le UA come variabili indipendenti e fornendo teoria e metodo adeguati per la manipolazione multidimensionale. Questo approccio è illustrato nel dominio della espressione del dolore prendendo come fattori le UA rilevanti per il dolore in compiti di integrazione tipici. I risultati rilevano che una regola additiva (sommativa e/o sottrattiva) governa la maggior parte degli aspetti della integrazione delle UA con un maggior contributo delle azioni sopra/sotto della parte inferiore della faccia. Più in generale, essi supportano i vantaggi e le aspettative di un approccio funzionale, opposto a tassonomico, alla elaborazione delle espressioni facciali.

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