WEEKLY EVENING MEETING,

Friday, January 27, 1893.

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The Just-Perceptible Difference.

WE seem to ourselves to belong to two worlds, which are governed by entirely different laws; the world of feeling and the world of matter—the psychical and the physical—whose mutual relations are the subject of the science of Psycho-physics, in which the just-perceptible difference plays a large part.

It will be explained in the first of the two principal divisions of this lecture that the study of just-perceptible differences leads us not only up to, but beyond, the frontier of the mysterious region of mental operations which are not vivid enough to rise above the threshold of consciousness. It will there be shown how important a part is commonly played by the imagination in producing faint sensations, and how its power on those occasions admits of actual measurement.

The last part of the lecture will deal with the limits of the power of optical discrimination, as shown by the smallest number of adjacent dots that suffice to give the appearance of a continuous line, and the feasibility will be explained of transmitting very beautiful outline drawings of a minute size, and larger and rougher plans, maps, and designs of all kinds, by means of telegraphy.

Material objects are measurable by external standards, about which it is sufficient to say that when we speak of a pound, a yard, or an hour, we use terms whose meanings are defined and understood in the same sense by all physicists. The feelings, on the other hand, cannot be measured by external standards, so we are driven to use internal ones, and to adopt a scale of sensation formed by units of just-perceptible differences, rising in the arithmetical order of 1, 2, 3, &c., and by their side a scale of measurements of the stimuli that provoked them. The attempts of those who first experimentalised in Psycho-physics were mainly directed to ascertain the relation between the increase of stimulus and the corresponding increment of sensation.

Their net result has been to confirm, within moderate limits, the trustworthiness of Weber's law, namely, that each successive increment of sensation is caused by the same *percentage* increment of the previous stimulus.

The rate at which a stimulus must be increased in order to give a just-perceptible increment of sensation, has been taken at the average of 1 per cent. for light, 6 per cent. for muscular effort, 33 per cent. for sound and warmth; also 33 per cent. for pressure upon most parts of the body, and as high as 16 per cent. upon the finger tips. But these values must not be trusted too far; they cease to be exact towards the two ends of the scale.

A mechanical arrangement clearly illustrates the consequences of Weber's law. It includes an axle to which is fixed a wheel, a part of a logarithmic spiral, and an index hand. This portion of the machine is carefully balanced, so that it will remain steady in any position in which it is set, while a small force is sufficient to cause it to turn; behind all is a card with equal graduations upon it, over which the index travels. A string, with a scale pan at one end and a counterpoise at the other, is wrapped round the wheel. A string fastened to the axle passes over the logarithmic arm, and a ball is fastened to its free end. The varying weights put in the scale pan will now represent varying amounts of stimulus, and the graduations to which the index points, represent the corresponding variations of sensation.

I exhibit a diagrammatic model of the apparatus, much too rough to give exact indications, but still sufficient for rough explanatory purposes.

Owing to the obvious properties of a spiral, the more the axle to which it is fixed is rotated in the direction of its concave side, the further does the point at which the string is hanging travel away from the axis, and the leverage exerted by the weight of the ball will increase. Whatever be the weight in the scale pan, there is within the working range of the apparatus some position of the beam at which that weight will be counterbalanced by the ball. The property of the logarithmic spiral is that equal degrees of rotation correspond to equal percentage increments of leverage. Hence, when percentage increments of weight are successively placed in the scale pan, the index attached to the beam will successively travel over equal divisions of the scale, in accordance with Weber's formula.

The progressive increase in the effective length of the logarithmic arm is small at first, but is seen soon to augment rapidly, and then to become extravagant. We thus gain a vivid insight through this piece of mechanism into the enormous increase of stimulus, when it is already large, that is required to produce a fresh increment of sensation, and how soon the time must arrive when the organ of sense, like the machine, will break down under the strain rather than admit of being goaded farther.

The result of all this is, that although the senses may perceive very small stimuli, and can endure very large ones without suffering damage, the number of units in the scale of sensation is comparatively small. The hugest increase of good fortune will not make a man who is already well off many degrees happier than before; the utmost torture that can be applied to him will not give much greater pain than he has already sometimes suffered. The experience of a life that we call uneventful usually includes a large share of the utmost possible range of human pleasures and human pains. Thus the physiological law which is expressed by Weber's formula is a great leveller, by preventing the diversities of fortune from creating by any means so great a diversity in human happiness.

The least-perceptible difference varies considerably in different persons, delicacy of perception being a usual criterion of superiority of nature. The sense of pain is curiously blunt in idiots. It varies also in the same person with his health, and extraordinarily so in hysteria and hypnotism, at which times sensitivity is sometimes almost absent, and at other times exceptionally acute. It is somewhat affected by drugs. Thus Dr. Lauder Brunton writes concerning strychnine, that when taken in small doses for a long time, the impressions are felt more keenly and are of longer duration. The sense of touch is rendered more acute; the field of vision is increased, distant objects are more distinct, and the sense of hearing is sharpened. (*Pharmacology*, 1885, p. 888.)

Other drugs or intoxicants may yet be discovered and legitimately used to heighten the sensitivity, or indeed any other faculty during a brief period, in order to perform that which could not otherwise be performed at all, at the cheap price of a subsequent period of fatigue.

Measure of the Imagination.—The first perceptible sensation is seldom due to a solitary stimulus. Internal causes of stimulation are in continual activity, whose effects are usually too faint to be perceived by themselves, but they may combine with minute external stimuli, and so produce a sensation which neither of them could have done singly. I desire now to draw attention to another concurring cause which has hitherto been unduly overlooked, or only partially allowed for under the titles of Expectation and Attention. I mean the Imagination, believing that it should be frankly recognised as a frequent factor in the production of a just-perceptible sensation. Let us reflect for a moment on the frequency with which the imagination produces effects that actually overpass the threshold of consciousness, and give rise to what is indistinguishable from, and mistaken for, a real sensation. Every one has observed instances of it in his own person and in those of others. Illustrations are almost needless; I may, however, mention one as a reminder; it was current in my boyhood, and the incident probably took place not many yards from where I now stand. Sir Humphry Davy had recently discovered the metal potassium, and showed specimens of it to the greedy gaze of a philosophical friend as it lay immersed in a dish of alcohol to shield it from the air, explaining its chemical claim to be considered a metal. All the known metals at that time were of such high specific gravity that weight was commonly considered to be a peculiar characteristic of metals; potassium, however, is lighter than water. The philosopher not being aware of this, but convinced as to its metallic nature by the reasoning of Sir Humphry, fished a piece out of the alcohol, and, weighing it awhile between his finger and thumb, said seriously, as in further confirmation, "How heavy it is!"

In childhood the imagination is peculiarly vivid, and notoriously leads to mistakes, but the discipline of after life is steadily directed to checking its vagaries and to establishing a clear distinction between fancy and fact. Nevertheless, the force of the imagination may endure with extraordinary power and even be cherished by persons of poetic temperament, on which point the experiences of our two latest Poets-Laureate, Wordsworth and Tennyson, are extremely instructive. Wordsworth's famous "Ode to Immortality" contains three lines which long puzzled his readers. They occur after his grand description of the glorious imagery of childhood, and the "perpetual benediction" of its memories, when he suddenly breaks off into—

> "Not for these I raise
> The song of thanks and praise,
> But for those obstinate questionings
> Of sense and outward things,
> Fallings from us, vanishings," &c.

Why, it was asked, should any sane person be "obstinately" disposed to question the testimony of his senses, and be peculiarly thankful that he had the power to do so? What was meant by the "fallings off and vanishings," for which he raises his "song of thanks and praise"? The explanation is now to be found in a note by Wordsworth himself, prefixed to the ode in Knight's edition. Wordsworth there writes, "I was often unable to think of external things as having external existence, and I communed with all I saw as something not apart from, but inherent in, my own immaterial nature. Many times while going to school have I grasped at a wall or tree to recall myself from this abyss of idealism to the reality. At that time I was afraid of such processes. In later times I have deplored, as we all have reason to do, a subjugation of an opposite character, and have rejoiced over the remembrances, as is expressed in the lines 'Obstinate questionings,' &c." * He then gives those I have just quoted.

It is a remarkable coincidence that a closely similar idea is found in the verses of the successor of Wordsworth, namely, the great poet whose recent loss is mourned by all English-speaking nations, and that a closely similar explanation exists with respect to them. For in Lord Tennyson's "Holy Grail" the aged Sir Percivale, then a monk, recounts to a brother monk the following words of King Arthur:—

> "Let visions of the night or of the day
> Come, as they will; and many a time they come
> Until this earth he walks on seems not earth,
> This light that strikes his eyeball is not light,
> The air that smites his forehead is not air,
> But vision," &c.

* Knight's edition of Wordsworth, vol. iv. p. 47.

Sir Percivale concludes just as Wordsworth's admirers formerly had done: "I knew not all he meant."

Now, in the *Nineteenth Century* of the present month Mr. Knowles, in his article entitled "Aspects of Tennyson," mentions a conversational incident curiously parallel to Wordsworth's own remarks about himself:—"He [Tennyson] said to me one day, 'Sometimes as I sit alone in this great room I get carried away, out of sense and body, and rapt into mere existence, till the accidental touch or movement of one of my own fingers is like a great shock and blow, and brings the body back with a terrible start.'"

Considering how often the imagination is sufficiently intense to mimic a real sensation, a vastly greater number of cases must exist in which it excites the physiological centres in too feeble a degree for their response to reach to the level of consciousness. So that if the imagination has been anyhow set into motion, it shall, as a rule, originate what may be termed *incomplete* sensations, and whenever one of these concurs with a real sensation of the same kind, it would swell its volume.

This supposition admits of being submitted to experiment by comparing the amount of stimulus required to produce a just-perceptible sensation, under the two conditions of the imagination being either excited or passive.

Several conditions have to be observed in designing suitable experiments. The imagined sensation and the real sensation must be of the same quality; an expected scream and an actual groan could not reinforce one another. Again, the place where the image is localised in the theatre of the imagination must be the same as it is in the real sensation. This condition requires to be more carefully regarded in respect to the visual imagination than to that of the other senses, because the theatre of the visual imagination is described by most persons, though not by all, as internal, whereas the theatre of actual vision is external. The important part played by points of reference in visual illusions is to be explained by the aid they afford in compelling the imaginary figures to externalise themselves, superimposing them on fragments of a reality. Then the visualisation and the actual vision fuse together in some parts, and supplement each other elsewhere.

The theatre of audition is by no means so purely external as that of sight. Certain persuasive tones of voice sink deeply, as it were, into the mind, and even simulate our own original sentiments. The power of localising external sounds, which is almost absent in those who are deaf with one ear, is very imperfect generally, otherwise the illusions of the ventriloquist would be impossible. There was an account in the newspapers a few weeks ago of an Austrian lady of rank who purchased a parrot at a high price, as being able to repeat the Paternoster in seven different languages. She took the bird home, but it was mute. At last it was discovered that the apparent performances of the parrot had been due to the ventriloquism of the dealer. An analogous trick upon the sight could not be performed by a conjuror. Thus he could never make his audience believe that the floor of the room was the ceiling.

As regards the other senses, the theatre of the imagination coincides fairly well with that of the sensations. It is so with taste and smell, also with touch, in so far that an imagined impression or pain is always located in some particular part of the body, then if it be localised in the same place as a real pain it must coalesce with it.

Finally, it is of high importance to success in experiments on Imagination that the object and its associated imagery should be so habitually connected that a critical attitude of the mind shall not easily separate them. Suppose an apparatus arranged to associate the waxing and waning of a light with the rising and falling of a sound, holding means in reserve for privately modifying the illumination at the will of the experimenter, in order that the waxing and waning may be lessened, abolished, or even reversed. It is quite possible that a person who had no idea of the purport of the experiment might be deceived, and be led by his imagination to declare that the light still waxed and waned in unison with the sound after its ups and downs had been reduced to zero. But if the subject of the experiment suspected its object, he would be thrown into a critical mood; his mind would stiffen itself, as it were, and he would be difficult to deceive.

Having made these preliminary remarks, I will mention one only of some experiments I have made and am making from time to time, to measure the force of my own imagination. It happens that although most persons train themselves from childhood upwards to distinguish imagination from fact, there is at least one instance in which we do the exact reverse, namely, in respect to the auditory presentation of the words that are perused by the eye. It would be otherwise impossible to realise the sonorous flow of the passages, whether in prose or poetry, that are read only with the eyes. We all of us value and cultivate this form of auditory imagination, and it commonly grows into a well-developed faculty. I infer that when we are listening to the words of a reader while our eyes are simultaneously perusing a copy of the book from which he is reading, that the effects of the auditory imagination concur with the actual sound, and produce a stronger impression than the latter alone would be able to make.

I have very frequently experimented on myself with success, with the view of analysing this concurrent impression into its constituents, being aided thereto by two helpful conditions, the one is a degree of deafness which prevents me when sitting on a seat in the middle rows from following memoirs that are read in tones suitable to the audience at large; and the other is the accident of belonging to societies in which unrevised copies of the memoirs that are about to be read, usually in a monotonous voice, are obtainable, in order to be perused simultaneously by the eye. Now it sometimes happens that

portions of these papers, however valuable they may be in themselves, do not interest me, in which case it has been a never-flagging source of diversion to compare my capabilities of following the reader when I am using my eyes, and when I am not. The result depends somewhat on the quality of the voice; if it be a familiar tone I can imagine what is coming much more accurately than otherwise. It depends much on the phraseology, familiar words being vividly represented. Something also depends on the mood at the time, for imagination is powerfully affected by all forms of emotion. The result is that I frequently find myself in a position in which I hear every word distinctly so long as they accord with those I am perusing, but whenever a word is changed, although the change is perceived, the new word is not recognised. Then, should I raise my eyes from the copy, nothing whatever of the reading can be understood, the overtones by which words are distinguished being too faint to be heard. As a rule, I estimate that I have to approach the reader by about a quarter of the previous distance, before I can distinguish his words by the ear alone. Accepting this rough estimate for the purposes of present calculation, it follows that the potency of my hearing alone is to that of my hearing *plus* imagination as the loudness of the same overtones heard at 3 and at 4 units of distance respectively; that is as about 3^2 to 4^2, or as 9 to 16. Consequently the potency of my auditory imagination is to that of a just-perceptible sound as $16-9$ to 16, or as 7 units to 16. So the effect of the imagination in this case reaches nearly half-way to the level of consciousness. If it were a little more than twice as strong it would be able by itself to produce an effect indistinguishable from a real sound.

Two copies of the same newspaper afford easily accessible materials for making this experiment, a few words having been altered here and there in the copy to be read from.

I will conclude this portion of my remarks by suggesting that some of my audience should repeat these experiments on themselves. If they do so, I should be grateful if they would communicate to me their results.

Optical Continuity.—Keenness of sight is measured by the angular distance apart of two dots when they can only just be distinguished as two, and do not become confused together. It is usually reckoned that the normal eye is just able or just unable to distinguish points that lie one minute of a degree asunder. Now, one minute of a degree is the angle subtended by two points, separated by the 300th part of an inch, when they are viewed at the ordinary reading distance of one foot from the eye. If, then, a row of fine dots touching one another, each as small as a bead of one 300th part of an inch in diameter, be arranged on the page of a book, they would appear to the ordinary reader to be an almost invisibly fine and continuous line. If the dots be replaced by short cross strokes, the line would look broader, but its apparent continuity would not be affected. It is impossible to draw any line that shall commend itself to the eye as possessing more regularity than the image of a succession of dots or cross strokes, 300 to the inch, when viewed at the distance of a foot. Every design, however delicate, that can be drawn with a line of uniform thickness by the best machine or the most consummate artist, admits of being mimicked by the coarsest chain, when it is viewed at such a distance that the angular length of each of its links shall not exceed one minute of a degree. One of the apparently smoothest outlines in nature is that of the horizon of the sea during ordinary weather, although it is formed by waves. The slopes of *débris* down the sides of distant mountains appear to sweep in beautifully smooth curves, but on reaching those mountains and climbing up the *débris*, the path may be exceedingly rough.

The members of an audience sit at such various distances from the lecture table and screen that it is not possible to illustrate as well as is desirable the stages through which a row of dots appears to run into a continuous line, as the angular distance between the dots is lessened. I have, however, hung up chains and rows of beads of various degrees of coarseness. Some of these will appear as pure lines to all the audience; others, whose coarseness of structure is obvious to those who sit nearest, will seem to be pure lines when viewed from the farthest seats.

Although 300 dots to the inch are required to give the idea of perfect continuity at the distance of one foot, it will shortly be seen that a much smaller number suffices to suggest it.

The cyclostyle, which is an instrument used for multiple writing, makes about 140 dots to the inch. The style has a minute spur-wheel or roller, instead of a point; the writing is made on stencil paper, whose surface is covered with a brittle glaze. This is perforated by the teeth of the spur-wheel wherever they press against it. The half perforated sheet is then laid on writing paper, and an inked roller is worked over the glaze. The ink passes through the perforations and soaks through them on to the paper below; consequently the impression consists entirely of short and irregular cross bars or dots.

I exhibit on the screen a circular letter summoning a committee, that was written by the cyclostyle. The writing seems beautifully regular when the circular is photographically reduced; when it is enlarged, the discontinuity of the strokes becomes conspicuous. Thus, I have enlarged the word *the* six times; the dots can then be easily seen and counted. There are 42 of them in the long stroke of the letter *h*.

The appearance of the work done by the cyclostyle would be greatly improved if a fault in its mechanism could be removed, which causes it to run with very unequal freedom in different directions. It leaves an ugly, jagged mark wherever the direction of a line changes suddenly.

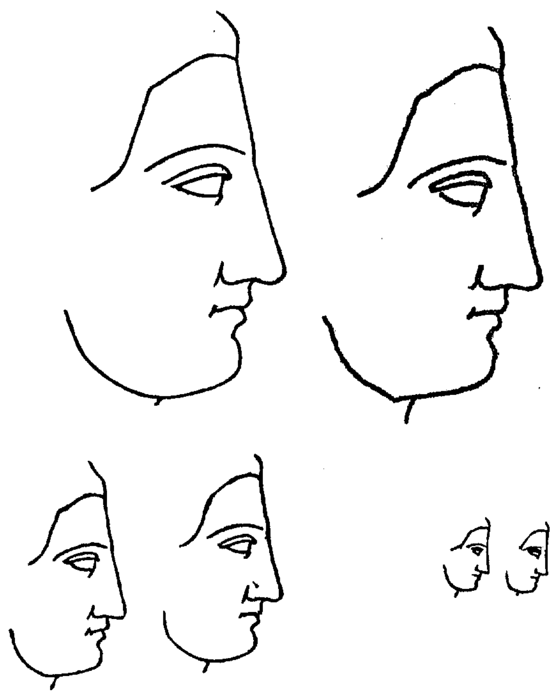
A much coarser representation of continuous lines is given by embroidery and tapestry, and coarser still by those obsolete school samplers which our ancestresses worked in their girlhood, with an average of about sixteen stitched dots to each letter. Perhaps the coarsest lettering, or rather figuring, that is ever practically employed is used in perforating the books of railway coupons so familiar to travellers. Ten or eleven holes are used for each figure.

A good test of the degree of approximation with which a cyclostyle making 140 perforations to the inch is able to simulate continuous lines, is to use it for drawing outline portraits. I asked the clerk who wrote the circular just exhibited to draw me a few profiles of different sizes, ranging from the smallest scale on which the cyclostyle could produce recognisable features, up to the scale at which it acted fairly well. I submit some specimens of the result. The largest is a portrait of $1\frac{1}{2}$ inches in height, by which facial characteristics are fairly well conveyed; somewhat better than by the rude prints that appear occasionally in the daily papers. It is formed by 366 dots. A medium size is $\frac{3}{4}$ inch high and contains 177 dots, and would be tolerable if it were not for the jagged strokes already spoken of. The smallest sizes are $\frac{1}{3}$ inch high and contain about 90 dots; they are barely passable, on account of the jagged flaws, even for the rudest portraiture.

I made experiments under fairer conditions than those of the cyclostyle, to learn how many dots, discs, or rings per inch were really needed to produce a satisfactory drawing, and also to discover how far the centres of the dots or discs might deviate from a strictly smooth curve without ceasing to produce the effect of a flowing line. It must be recollected that the eye can perceive nothing finer than a minute blur of one 300th part of an inch in angular diameter. If we represent a succession of such blurs by a chain of larger discs, it will be easily recognised that a small want of exactitude in the alignments of the successive discs must be unimportant. If one of them is pushed upwards a trifle and another downwards, so large a part of their respective areas still remains in line, that when the several discs become of only just perceptible magnitude, the projecting portion will be wholly invisible. When the discs are so large as to be plainly perceptible, the alignment has to be proportionately more exact. After a few trials it seemed that if the *bearing* of the centre of each disc from that of its predecessor which touched it, was correctly given to the nearest of the 16 principal points of the compass, N., NNE., NE., &c., it was fairly sufficient. Consequently a simple record of the successive bearings of each of a series of small equidistant steps is enough to define a curve.

The briefest way of writing down these bearings is to assign a separate letter of the alphabet to each of them, *a* for north (the top of the paper counting as north), *b* for north-north-east, *c* for north-east, and so on in order up to *p*. This makes *e* represent east, *i* south, and *m* west.

To test the efficiency of the plan, I enlarged one of the cylostyle profiles, and making a small protractor with a piece of tracing paper, rapidly laid down a series of equidistant points on the above principle, noting at the same time the bearing of each from its predecessor. I thereby obtained a formula for the profile, consisting of 271 letters. Then I put aside the drawing, and set to work to reproduce it solely from the formula. I exhibit the result; it is fairly successful. Emboldened by this first trial, I made a more ambitious attempt, by dealing with the profile of a Greek girl copied from a gem. I was very desirous of learning how far the pure outline of the original admitted of being mimicked in this rough way.



The result is here; a ring has been painted round each dot in order to make its position clearly seen, without obliterating it. The reproduction has been photographically reduced to various different sizes. That which contains only fifty dots to the inch, which is consequently six times as coarse as the theoretical 300 to an inch, is a very creditable production. Many persons to whom this portrait has been shown, failed to notice the difference between it and an ordinary woodcut. The medium size, and much more the smallest size, would deceive anybody who viewed them at the distance of one foot. The protractor used in making them was a square card with a piece cut

out of its middle, over which transparent tracing paper was pasted. A small hole of about $\frac{1}{8}$ of an inch in diameter was punched out of the centre of the tracing paper; sixteen minute holes just large enough to allow the entry of the sharp point of a hard lead-pencil were perforated through the tracing paper in a circle round the centre of the hole at a radius of $\frac{1}{4}$ inch. They corresponded to the sixteen principal points of the compass, and had their appropriate letters written by their sides. The outline to be formulated was fixed to a drawing-board, with a T rule laid across it as a guide to the eye in keeping the protractor always parallel to itself. The centre of the small hole was then brought over the beginning of the outline, and a dot was made with the pencil through the perforation nearest to the further course of the outline, and this became the next point of departure. While moving the protractor from the old point to the new one it was stopped on the way, in order that the letter for the bearing might be written through the central hole. These were afterwards copied on a separate piece of paper.

A clear distinction must be made between the proposed plan and that of recording the angle made by each step from the *preceding one.* In the latter case, any error of bearing would falsify the direction of all that followed, like a bend in a wire.

The difficulties of dealing with detached portions of the drawing, such as the eye, were easily surmounted by employing two of the spare letters, R and S, to indicate brackets, and other spare letters to indicate points of reference. The bearings included between an R and an S were taken to signify directive dots, not to be inked in. The points of reference indicated by other letters are those to which the previous bearing leads, and from which the next bearing departs. Here is the formula whence the *eye* was drawn. It includes a very small part of the profile of the brow, and the directive dots leading thence to the eye.

The letters should be read from the left to the right, across the vertical lines. They are broken into groups of five, merely for avoiding confusion and for the convenience of after reference.

The part of the Profile that includes U

&c. iiiilU jiihi &c. &c.

The Eye.

URkkk mlmlm mmnZZ onooZ	kklll llmZZ Tjjjj	mSVap VnTnn jjkkc	ponmn mnmmm chmmn	mmlmm mmmlm mnnn

Letters used as Symbols.

R....S=(....). Z=end.
U, V, T are points of reference.

By succeeding in so severe a test case as this Greek outline, it may be justly inferred that rougher designs can be easily dealt with in the same way.

At first sight it may seem to be a silly waste of time and trouble to translate a drawing into a formula, and then, working backwards, to retranslate the formula into a reproduction of the original drawing, but further reflection shows that the process may be of much practical utility. Let us bear two facts in mind, the one is that a very large quantity of telegraphic information is daily published in the papers, anticipating the post by many days or weeks. The other is that pictorial illustrations of current events, of a rude kind, but acceptable to the reader, appear from time to time in the daily papers. We may be sure that the quantity of telegraphic intelligence will steadily increase, and that the art of newspaper illustration will improve and be more resorted to. Important local events frequently occur in far-off regions, of which no description can give an exact idea without the help of pictorial illustration; some catastrophe, or site of a battle, or an exploration, or it may be some design or even some portrait. There is therefore reason to expect a demand for such drawings as these by telegraph, if their expense does not render it impracticable to have them. Let us then go into details of expense, on the basis of the present tariff from America to this country, of one shilling per word, 5 figures counting as one word, cypher letters not being sent at a corresponding rate. It requires two figures to perform each of the operations described above, which were performed by a single letter. So a formula for 5 dots would require 10 figures, which is the telegraphic equivalent of 2 words; therefore the cost for every 5 dots telegraphed from the United States would be 2 shillings, or 2*l.* for every 100 dots or other indications.

In the Greek outline there is a total of 400 indications, including those for directive dots, and for points of reference. The transmission of these to us from the United States would cost 8*l.* I exhibit a map of England made with 248 dots, as a specimen of the amount of work in plans, which could be effected at the cost of 5*l.* It is easy to arrange counters into various patterns or parts of patterns, learning thereby the real power of the process. The expense of pictorial telegraphs to foreign countries would be large in itself, but not large relatively to the present great expenditure by newspapers on telegraphic information, so the process might be expected to be employed whenever it was of obvious utility.

The risk is small of errors of importance arising from mistakes in telegraphy. I inquired into the experience of the Meteorological Office, whose numerous weather telegrams are wholly conveyed by numerical signals. Of the 20,625 figures that were telegraphed this year to the office from continental stations, only 49 seem to have been erroneous, that is two and a third per thousand. At this rate the 800 figures needed to telegraph the Greek profile would have been liable to two mistakes. A mistake in a figure would have exactly the same effect on the outline as a rent in the paper on which

a similar outline had been drawn, which had not been pasted together again with perfect precision. The dislocation thereby occasioned would never exceed the thickness of the outline.

The command of 100 figures from 0 to 99, instead of only 26 letters, puts 74 fresh signals at our disposal, which would enable us to use all the 32 points of the compass, instead of 16, and to deal with long lines and curves. I cannot enter into this now, nor into the control of the general accuracy of the picture by means of the distances between the points of triangles each formed by any three points of reference. Neither need I speak of better forms of protractor. There is one on the table by which the ghost of a compass card is thrown on the drawing. It is made of a doubly refracting image of Iceland spar, which throws the so-called "extraordinary" image of the compass card on to the ordinary image of the drawing, and is easy to manipulate. All that I wish now to explain is that this peculiar application of the law of the just-perceptible difference to optical continuity gives us a new power that has practical bearings.

Postscript.—A promising method for practical purposes that I have tried, is to use "sectional" paper; that is, paper ruled into very small squares, or else coarse cloth, and either to make the drawing upon it, or else to lay transparent sectional paper or muslin over the drawing. Dots are to be made at distances not exceeding three spaces apart, along the course of the outline, at those intersections of the ruled lines (or threads) that best accord with the outline. Each dot in succession is to be considered as the *central point*, numbered **44** in the following

11	21	31	41	51	61	71
12	22	32	42	52	62	72
13	23	33	43	53	63	73
14	24	34	**44**	54	64	74
15	25	35	45	55	65	75
16	26	36	46	56	66	76
17	27	37	47	57	67	77

schedule, and the couplet of figures corresponding to the portion of the next dot is to be written with a fine-pointed pencil in the interval between the two dots. These are subsequently copied, and make the formula. By employing 4 for zero, the signs + and − are avoided; 3 standing for −1, 2 for −2, and 1 for −3. The first figure in each couplet defines its horizontal coordinate from zero; the second figure, its vertical one. Thus any one of 49 different points are indicated, corresponding to steps from zero of 0, ±1, ±2, and ±3 intervals, in either direction, horizontal or vertical. Half an hour's practice suffices to learn the numbers. The figures 0, 8, and 9 do not enter into any of the couplets in the schedule, the remaining 51 couplets in the complete series of 100 (ranging from 00 to 99), contain 21 cases in which 0, 8, or 9 forms the first figure only; 21 cases in which one of them forms the second figure only; and 9 cases in which both of the figures are formed by one or other of them. These latter are especially distinctive. This method has five merits—medium, short, or very short steps can be taken according to the character of the lineation at any point; there is no trouble about orientation; the bearings are defined without a protractor, the work can be easily revised, and the correctness of the records may be checked by comparing the sums of the successive small co-ordinates leading to a point of reference, with their total value as read off directly.

A method of signalling is also in use for military purposes, in which positions are fixed by co-ordinates, afterwards to be connected by lines.

[F. G.]